SPACE AND HUMAN DEVELOPMENT

Prof. Mohan Sundara Rajan

GANDHI CENTRE
OF
SCIENCE AND HUMAN VALUES
OF
BHARATIYA VIDYA BHAVAN

Bangalore - 560 001

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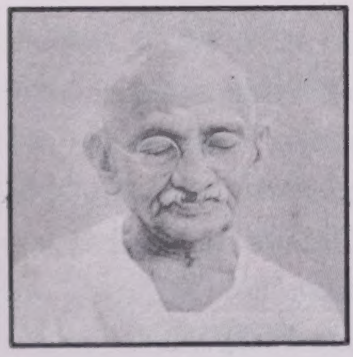

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FOREWORD

Bhavan's Gandhi Centre of Science and Human Values has become increasingly popular with the student community because of its researched publications on the culture and values as also on account of the Students' interface programmes conducted in different Educational Institutions both in Bangalore and outside.

The central theme of the publication project is Gandhian wisdom on various issues of contemporary relevance. But it is considered essential to include may other themes and subjects which have social and scientific relevance. Gandhiji himself said that he welcomed advancement of science and technology for solving our problems. That is the reason why some of the outstanding scientists of the country were approached for writing about the achievements in the respective area of their specialisation. I was happy to see the enthusiastic response from them to write for the young on scientific themes. I am grateful to the scholars who have obliged the Bhavan's Gandhi Centre with their contribution.

I do earnestly hope that the young people including students will benefit reading these short treatises.

I am particularly beholden to Mohan Sundara Rajan for writing out the present little volume on SPACE AND HUMAN DEVELOPMENT.

RAJA RAMANNA

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1

SPACE AND HUMAN DEVELOPMENT : GLOBAL TRENDS

The Space Age began in 1957 with the launch of the Russian satellite, Sputnik. The event jolted the Americans into a space race with the Russians. When Neil Armstrong landed on the moon in 1969, the Americans claimed that only they could achieve that first-ever feat. The Russians with unmanned satellites proclaimed that they would win the space race. National pride marked their claims.

Today the situation is quite different. No longer is space technology considered the monopoly of a few super powers. Space is now regarded as the common heritage of humankind.

In a world without the Cold War, Western countries have turned to space as their new arena for commercial ventures. Space is now big business. Commercial space activities, propelled by giant corporations, have far exceeded the civilian space expenditure of all governments put together. It is of the order of $ 120 billion annually.

The huge expenditure is due to space-based applications, which have become the basis of economic planning in many countries. New markets have emerged for space products and services. The trend has been strengthened by globalisation of national economies, deregulation and the emergence of knowledge-based technologies.

The encouraging picture has, however, another side. The impact of space technology on developing countries, except a few, has been minimal. For example, the telecommunication industry is attracting investments worth more than $ one trillion, but half the world's population have not made a single phone call ! Nearly 84 per cent of all mobile cellular subscribers, 91 per cent of all fax machines and 97 per cent of all Internet host computers are located in developed countries. On the other hand, 40 per cent of the world's population are illiterate. And 25 per cent do not have access to clean drinking water.

Developing countries therefore call for a better deal. Technology transfer, they demand, should be on an equitable basis, even if it is on commercial terms. And commercial ventures would be sustained in the long term only if developing countries advance and undertake space applications. Developing countries do welcome competition as a means of securing cost-effective technologies but hold that it should not result in exploitation. Technical cooperation could narrow the gap between the haves and have-nots in this field.

A key requirement for reaping the benefit of space is low-cost access to orbits. The commercial launch vehicle industry is forecast to expand at 10 per cent annually. By 2006, 260 to 310 commercial satellites are expected in the geostationary orbit alone (at 36,000 km above the equator), involving an expenditure of $ 30 billion. A study indicates that the total number of satellites in all Earth orbits will go up to 1700 by 2010 as against 700 operating satellites at present. The market is still driven by big satellites, though small satellites would supplement them. The cost of launching a satellite is still a major component in space applications.

Developing countries are interested in four major areas of space application viz., telecommunications including data transfer and television, remote sensing, expansion of global navigation systems, disaster warning and mitigation. In the field of telecommunications, several developing countries which do not have adequate conventional facilities, would be able to leap-frog into the Space Age. The emergence of new technologies such as wireless links and cable upgradation has opened the door to widespread use of the Internet. Though the geostationary orbit is getting crowded with international and national satellites, satellites in that orbit are essential for developing countries for their domestic as well as international voice, data, TV and Internet connections. The communication satellites in the lower Earth orbits are yet to become cost-effective. In fact, two international companies that sought to provide mobile phone services form lower Earth orbits, ran into financial troubles.

In the field of remote sensing, the Internet has made satellite imageries virtually available at the finger-tips of users. By 2002, 20 new remote sensing satellites are due for launch. However, commercial charges for imageries are still quite high for many developing countries. Moreover, the flood of satellite data is not being utilised in the Asian and Pacific region as much as in Europe. This is rather paradoxical, as the Region has emerged as a dynamic area in this field, with 11 ground stations for remote sensing data capture and 20,000 remote sensing experts.

Disaster warning and mitigation of damage is vital to developing countries, as 90 per cent of all national disasters and 95 per cent of the related loss of life occur in these countries. However, there is at present no machanism that connects the disaster management community with the operators of satellite systems. Only a handful of countries have the telecommunication facilities for coping with disasters. Our knowledge base for understanding the weather and the influence of the oceans is far from adequate.

Another area of interest to developing countries is satellite navigation including the global positioning system. Users of the system must see four satellites to determine their three-dimensional position. The Americans provide such a reference signal service free of charge through their geographic positioning system (GPS) satellites. The Russians also provide similar satellites. The Europeans have proposed a big system called Galileo for providing better accuracy in location but as a priced service. A sensitive issue would, however, be the sharing of costs of the services.

Technology transfer in space-based applications has become difficult. Hence, India has developed its space programme on a self-reliant basis, even if that meant delay and disappointment in the initial period. Again, when space applications are designed and implemented on a commercial basis, the Indian space programme has given importance to human development that would benefit the largest possible number of beneficiaries from various walks of life. In designing such a programme, the country's scientists and engineers have played a key role.

2

A THOUSAND YEARS BEFORE COPERNICUS

About a thousand years before the Polish astronomer, Nicolaus Copernicus (1473-1543), published his theory (in 1543 A.D.) that the Earth revolved round the sun, an Indian astronomer, Aryabhata (born in 476 A.D.) outlined the sun-centric theory in 499 A.D. Aryabhata illustrated his idea by an analogy. People on the Earth felt that the sun was moving, he said, just as a person going on a boat in a river saw the trees on the bank moving away. Aryabhata stated that the Earth was round, and that it rotated on its axis, orbiting the sun and floating in space—remarkable findings in the days when there were no telescopes. He explained the eclipses scientifically and pointed out how the shadows of the sun, the moon and the Earth caused lunar and solar eclipses.

In an amazing feat of calculation, Aryabhata held that the distance travelled by a planet would be equal to the circumference of a great circle illuminated by the sun in a *yuga*, which he defined as a division of time, equal to 4,320,000 years. He further held that 1003 yugas constituted a day of Brahma (creator of life according to Hindu belief and mythology), which adds upto 4,320 million years. The estimate is pretty close to the modern calculation of the age of the Earth.

About 1200 years before Isaac Newton (1642-1727), Bhaskaracharya, an astronomer of the sixth century A.D. stated that objects fell to the Earth because of a force of attraction by the Earth. He further pointed out that the Earth, other planets, the moon, the sun and the constellation of stars are all held in their orbit by the force of attraction. He even calculated the time taken by the Earth to orbit the sun up to nine decimal places, differing only 0.0002 per cent from the modern measurement.

The decimal system flourished in India long before the Christian era. It is widely accepted that the concept of zero originated in India. Sanskrit works of the fourth century B.C. referred to the idea as *Shunya*. Brahmagupta (7th century A.D.) lucidly explained the concept. The idea was later picked up in Arabia.

Inventor of Wireless Communication

An invention of great importance to the Space Age had been indeed made and demonstrated by a patriotic Indian scientist over a hundred years ago.

Swami Vivekananda persuaded him to file a patent in the United States for one of his inventions. Gurudev Tagore composed a poem in praise of the inventor. The discoverer of the particle, electron, Sir J.J. Thompson wrote a foreword to a book of research papers by the Indian inventor. Lord Kelvin simply admired him.

He was Prof. Jagadis Chander Bose, inventor of wireless communication (1858-1937). But the world almost forgot his contribution.

Recently, a group of scientists of the Institute of Electronics and Electrical Engineers in the United States confirmed that Prof. Bose was the inventor of the world's first solid-state diode detector of wireless waves. It is now known that the detector used by Guglielmo Marconi (1874-1937) to pick up the wireless signal across the Atlantic ocean in the form of the Morse code signal of three dots representing the letter 'S' in 1901 was invented by Prof. Bose. The fact, perhaps unknown to Marconi, was submerged in the chorus of praise for the Italian's pioneering work in using the invention.

The eminent Indian's seminal paper was published in the January 1897 issue of the Proceedings of the Royal Society in England. *The Times*, London and *Daily Chronicle* had reported the invention correctly in 1896 and disclosed that Prof. Bose had transmitted signals to a distance of nearly a mile. Even in May 1895 Prof. Bose read a paper at the Asiatic Society of Bengal describing how he had generated electromagnetic waves of about five millimetre wavelength. In the town hall of Calcutta, he transmitted the waves through the body of the chairman of the meeting, the Lt. Governor of Bengal to ring a bell and explode a mine in a closed room! Bose's work was commended by Lord Rayleigh. Bose was knighted in 1917 and made a member of the Royal Society in 1920.

When Bose was a Professor of Physics in the Presidency College in Calcutta, he did not accept his salary for three years as he was paid less than his equivalent English staff. Bose eventually won the case. It was only after two years of his filing for the US patent, did the work on solid state wireless detector start in the U.S. Also, it is now proved that C.F. Braun, who shared the Nobel Prize for Physics with Marconi, entered the wireless telegraphy arena only in 1898, some three years later than Bose.

The Indian tradition of scholarship, marked by its quest for new frontiers of knowledge, was revived by the Space Age.

3

A UNIQUE VISIONARY

He was a scientist with a difference. His intellectual attainments were remarkable. But pure science alone would not satisfy him. He was fascinated with the power of science and technology as a means of initiating socio-economic change for the millions of people in his country. He was a unique visionary who launched the people of his country into the Space Age. He was Dr. Vikram Sarabhai.

Born in 1919 in Ahmedabad, Vikram was educated at the family school directed by his mother. He later studied at the Gujarat college in Ahmedabad and received a Bachelor's degree in Natural Science from St. John's College, U.K. in 1939. In 1947 he earned his doctorate from the Cambridge University for his research in photofission at the Cavendish Laboratory.

Young Vikram was inspired by Dr. Homi Bhabha (1909-1966) who studied cosmic rays from outer space at the Indian Institute of

Science, Bangalore in the 1940s. Vikram was also attracted by the subject, when he worked with the Nobel Laureate Dr. C.V. Raman (1888-1970) in India.

On his return to India from Cambridge in 1947, Dr. Sarabhai, who was only 28, started a research laboratory and within a year founded the Physical Research Laboratory in Ahmedabad for the study of cosmic rays and atmospheric physics.

The dawn of the Space Age fascinated Dr. Sarabhai. The discovery of the Van Allen radiation belts around the Earth by the first American Satellite, Explorer-1, revealed a new frontier in science and technology. The Tata Institute of Fundamental Research, Mumbai, undertook studies of the ionosphere (the radio mirror of the sky) and cosmic phenomena. The Institute conducted balloon experiments from Hyderabad. An optical satellite tracking station was built in Nainital in Uttar Pradesh with assistance from the Smithsonian Astrophysical Observatory in the United States. The National Physical Laboratory, New Delhi, conducted experiments on radio waves.

Dr. Sarabhai envisaged a wider role for space technology. An Indian National Committee for Space Research (INCOSPAR) under his Chairmanship, was set up in 1962 to realise the potential of space technology for the uplift of the people. The Space Age was only five years old, when he outlined a space programme for India. The use of space for such applications as communications, was still an experiment elsewhere. He persuaded Pandit Nehru to allow government investment in the new field of Science and Technology. He envisaged that space would offer a solution to many development problems such as poor communication facilities, illiteracy and inadequate education and indiscriminate exploitation of natural resources.

An area which readily attracted Dr. Sarabhai's attention is the atmosphere above the Earth's magnetic equator, running close to its geographic equator. He chose Thumba on the West Coast, near the magnetic equator for establishing a rocket launching station, for the study of the atmosphere. The station was set up in 1963.

By coincidence, the world's first successful synchronous satellite, Syncom II, was also launched in 1963. Next year, the Tokyo Olympics was relayed to the United States by a satellite.

Dr. Sarabhai and his colleagues envisaged a critical role of space communications in India and planned a centre for working with communication satellites. In 1964 they decided to set up such a centre in Ahmedabad and built it in a record time of 87 days.

Meanwhile, the United Nations accorded its sponsorhip to the Thumba range in 1965 as an international facility open to all members for launching sounding rockets for peaceful purposes. The range was made available to any nation which desired to conduct peaceful experiments in space.

Dr. Sarabhai realised the scope for space technology, particularly in the field of communication, meteorology and remote sensing. He was aware of the ever-widening gap between the developed and developing countries in the economic and social fields. He pointed out that developing countries could simply not afford to go step by step, because such a course would be defeated even before it made a beginning.

He argued the case of developing countries at the United Nations Conference on the Exploration and Peaceful Use of Outer Space in 1968. In his presidential address to the Conference he said, *"...a positive approach for a way out of this predicament seems to lie in finding solutions where the particular disadvantage of developing nations, which is that they have little to build on, is made an asset rather than a liability. I suggest that it is necessary for them to develop competence in advanced technologies and to deploy them for the solution of their own particular problems, not for prestige, but based on sound technical and economic evaluation involving commitment of real resources. They (developing countries) would discover that there is a totality about the process of development which involves not only advanced technology and hardware but imaginative planning of supply and consumption centres, of social organisation and management to leap-frog from a state of backwardness and poverty"*.

Following the UN Conference, Sarabhi initiated a countrywide satellite TV broadcasting experiment in 1969, the year in which man landed on the moon for the first time. The idea took shape as the Satellite Instructional Television Experiment (SITE) in 1975 using an American satellite.

On the role of industrially advanced countries, he plainly said *"they often play a negative role in their interaction with the developing countries. There is seduction by their political and commercial salesmen who dangle new gimmicks, which they suggest should be imported rather than indigenous capability be developed and supported"*.

There was no question of compromise and acceptance of second rate technology by developing nations. *"If we are to play a meaningful role nationally and in the community of nations, we must be second to none in the application of advanced technologies to the real problems of man and society"*.

Even as he advocated modern technology, Sarabhai was emphatic that the use of technology should be governed by certain values that respect the grandeur and supremacy of Nature.

"The peaceful exploration of outer space, has opened our eyes and made us realise that the earth itself is a self-contained spacecraft and human beings on it are the passengers, ...we not only face the danger of running out of resources, but also of polluting the air and water on which our survival depends. Space technology can be put to action effectively on an international scale to cope with some of the immense problems of under-development".

Sarabhai died suddenly in 1971. The unexpected end of such a dynamic career at a young age came as a rude shock to the nation. His benign presence, his innovative solutions and practical words of wisdom became inspiring memories.

In a rare tribute, Sarabhai's name was inducted into the International Space Hall of Fame at the Space Centre, Alamogordo, New Mexico in 1993. He joined the Hall's illustrious list of pioneers in space technology such as Robert Goddard, Werner von Braun, Arthur Clarke, Yuri Gagarin and Neil Armstrong.

Sarabhai practised what he preached. A younger generation of scientists who took charge of space activities fortunately shared his vision of space technology and accordingly based it on certain values that enhanced the quality of human life and restored the dignity of the underprivileged. The predominant applications were therefore identified in the areas of education, communication, agriculture and national resource management. Never before in the history of development, was such a high-flying technology pegged to so many socially meaningful ground truths. Space became the popular icon of human development.

4

A JOURNEY FROM THE CYCLE AGE

Even as the pioneering scientists cycled their way to the seashore of Thumba in Kerala, they were determined to leap-frog into the Space Age. As they assembled the parts of simple rockets, they realised that going into space would involve a complete mastery of the fundamentals of rocket technology.

A satellite will be in a circular orbit of the Earth, if it attains a velocity of 8 kilo meters(km) a second or 28,000 km an hour at a minimum height of about 150 km. If it exceeds the speed, the orbit becomes elliptical. If it reaches 11.26 km/sec or 40,000 km/hour, it can escape the immediate gravity of the Earth.

Long before the Space Age, Galileo had pointed out that the Earth's gravity would force a falling body to come down at 980 cm a second after every second, which is the force experienced at sea level (9.81 m/s^2). It was a great discovery.

The Earth's gravity attracted Newton's attention. He formulated a law : if the distance from the Earth is doubled, then the pull of gravity is reduced to a quarter. A velocity of 1.6 km/s can take an object to a maximum height of 130 km. If, however, the initial velocity is 9.6 km/s, then the object can go upto 17,900 km.

Newton's laws govern a rocket's motion. In fact, Newton had illustrated how an object could be in orbit around the Earth, given the correct velocity. His third law – simply illustrated by a frog jumping off a floating twig in a pond – applies to a rocket, when the fuel and oxidiser are brought into a combustion chamber to ignite and form a gas that escapes at high velocity pushing the rocket in the opposite direction. Newton's first law that a body will remain at rest or in a state of motion in a straight line unless acted upon by an external force, formed the basis of a rocket's guidance systems.

The thrust to a rocket is provided by chemical propellants, which may be liquid or solid. In a solid propellant rocket, the fuel and the oxidiser are mixed in a solid form.

The rocket casing serves as the burning chamber. A liquid propellant rocket can either use a single propellant (which is decomposed to produce a jet) or different fuels that can be burnt in the chamber. The liquid propellants can be taken into the burning chamber using either high-pressure gas or a high-speed pump.

Rocketry was not completely new to India. In the 18th century, Hyder Ali and Tippu, rulers of Mysore, used rockets with gun powder inside in the war against the British. The rockets produced a jet of gas that propelled them to three kilometers. The thrust produced was, however, quite feeble and uncontrolled. Nevertheless, models of the rocket were taken by the British to England and William Congreve, the Younger made similar missiles for use in a war in Europe.

Today's chemical rockets are sophisticated vehicles. When a small group of scientists began their rocket studies in an old church in Thumba in the early sixties, they had to start it all from the scratch. There was neither a foreign source of assistance nor a domestic missile programme to follow. Indian industry too was not geared to the idea. Though the scientists mastered the theory, turning it into practice indicated a long road ahead of them.

The first sounding rocket, launched from Thumba in 1960, was called Nike-Apache, brought from the United States. The mission of the four scientists who brought the rocket was simply to assemble the rocket, launch it and study the payload deployment. The hydraulic crane failed in the first attempt. But the scientists did not give up. Together with the local people, they lifted the rocket on to a trolley and moved it away for a successful launch.

Dr. Sarabhai had arranged an agreement with France, which allowed the manufacture of two-stage Centaure rockets in India. The first three Centaurs were made in Mumbai by the Bhabha Atomic Research Centre. Later, they were fabricated in Thumba itself.

Meanwhile, work started on indigenous sounding rockets. A Space Science and Technology Centre was set up in Thumba in 1965. It was later renamed Vikram Sarabhai

Space Centre, as a tribute to the architect of the country's space programme. The centre was entrusted with the task of designing, developing and launching sounding rockets and providing launchers for ISRO's satellites. Four years after the launch of the first foreign rocket, an indigenous rocket, RH-75 was launched on November 20, 1967. Some critics ridiculed it as a toy rocket. But those who were aware of the challenges knew that it was not child's play. In 1969 a Centaure with an Indian propellant was launched. It was found that the payload reached five kilometers higher than expected.

With the commissioning of a Rocket Fabrication Facility in 1971 in Thumba, regular production of sounding rockets started. The diameter of the rockets (given in millimetres) increased steadily. A Rohini-300 was made and launched in 1973, followed by a two-stage Rohini-500 in 1975. The latter could reach an altitude of 360 km with a 90kg payload.

Meanwhile, a Rocket Propellant Facility and a Propellant Fuel Complex were added to the facilities in Thumba.

VSSC was given the challenging task of achieving self-reliance in space technology in line with Dr. Sarabhai's dream. The goal needed proven expertise in several disciplines: flight dynamics, wind tunnels, applied mathematics, navigation, guidance and control, inertial systems, materials science, metallurgy and fabrication of subsystems for satellites. Separate departments were set up in the VSSC to master these technologies.

The big challenge was in making the propellants for the rockets. A propellant provides energy to a rocket, which carries oxygen to burn it. (Air-breathing rockets are still in the experimental stage). A propellant can be solid or liquid. A solid propellant, once ignited, cannot be switched off. A composite solid propellant mainly consists of an oxidiser (such as ammonium perchlorate), fuel and a fuel binder. The technology of making ammonium perchlorate directly from sodium chloride was based on the know-how developed by the Central Electro-Chemical Research Institute, Karaikudi. The fuel (viz., polyvinyl chloride) is mixed with a binder (e.g.

carboxy terminated polybutadiene) and an oxidiser is added. Propellants with varying burn rates and thrust to suit different rockets were made. Their quality was evaluated in high-altitude simulation tests.

Liquid propellant rocket engines can be switched on and off. They are therefore used in control motors as well as in various stages in a rocket. Liquid rockets can be designed to work either on a monopropellant or a bipropellant. A monopropellant such as hydrazine has both fuel and oxidiser. A catalyst is used to decompose it into constituent gases. A bipropellant has fuel and oxidiser, separately sent to a combustion chamber. Storable liquid propellant can be kept at terrestrial temperature, while the non-storable propellant is cooled to keep it liquid. Liquid propellant rockets can be designed in two different ways viz., pressure-fed or pump-fed. In the former, a high pressure gas (e.g. helium) pushes the fuel and the oxidant, while in the latter, a turbine pumps the fuel and oxidant into a combustion chamber. The nozzle of a rocket, (its shape size and strength) will vary the thrust.

The first indigenous liquid rocket was aunched in 1973. Several liquid propellants ere developed (e.g. unsymmetrical imethyl-hydrazine-UDMH). The know-how as since been transferred to a public sector ompany for production.

An Island of Hope

A solid rocket cannot be test-fired before aunch. With a view to avoiding the transport f big propellant blocks to the launching ange in the east coast, a solid propellant lant was set up in Sriharikota, a small sland, 80 km north of Chennai.

Moreover, a rocket launched from India's ast coast near the equator can get extra ush from the Earth's eastward rotation. Dr. arabhai and his colleagues therefore chose riharikota. At 13°N latitude, it is the nearest vailable rocket range on India's east coast rom the equator. Thumba was continued as e equatorial rocket range for scientific tudies.

The spindle-shaped island is sandwiched etween the Bay of Bengal on the east and ulicat Lake on the west. The island is

44 km long and 7.8 km wide at its broad stretch. It was chosen, following an aer survey of the east coast in 1969.

Sriharikota is rich in vegetation with t streams flowing parallel to each other in t middle of the island. A survey made by t scientists of Sri Venkateswara University h identified over 400 species of plants includ some rare varieties. The island has evergre forests, scrubs, plantation, seasho vegetation, and aquatic plants. Eucalypt casuarina, coconut and palmyrah a prominently seen. A rich and varied flo wealth has also been found.

Space scientists are keen to preserve t natural beauty of the island. The Yenadh the only few inhabitants of the island, ha been rehabilitated.

A road connecting the island to Sullurpe the nearest town, was laid. The rocket ran in the island became operational on Octo 9, 1971 with the launch of a 125 mm Roh sounding rocket. The range has facilities testing and launching bigger rockets a equipment for tracking and command them.

A 3500 - tonne mobile service tower, 76 m tall and a mission control centre, six km away have been set up on the island.

Following the successful launch of PSLVs, the range has been upgraded for the bigger geostationary satellite launch vehicle (GSLV). A second launching pad is under construction.

5

ROCKETS : NO SHORT - CUTS

The sounding rockets made in Thumba for scientific investigations were of various sizes, their diameter ranging from 200 mm to 560 mm. The rockets could carry payloads upto 200 kg to an altitude of 300-400 km. The programme enabled the rocket engineers to gain experience in building bigger rockets.

The size and weight of the propellant segments and the rocket motors made in Thumba determined the basic design of bigger rockets built for launching satellites.

The First Satellite Launcher

About 12 years after the first rocket was launched, work on the first Satellite Launch Vehicle (SLV) was completed. Called SLV-3, it weighed 17 tonnes, including 13 tonnes of propellants. The rocket had four stages, its total length being 22.7 metres. Three rocket motor segments were linked into one for the first stage.

SLV-3 was launched in 1979. Data received from the rocket revealed that the vehicle started tumbling after lift-off. Five minutes and 15 seconds after the lift-off, the rocket plunged into the Bay of Bengal with its 40 kg technological payload. It was a flop, though 70 per cent of the systems had worked normally. It was later found that a valve had jammed in the second stage and that led to the eventual failure.

The mission gave confidence to the pioneers, though it showed that there were no short-cuts to success. Work continued on the second SLV-3. A year later (in 1980), the second experimental rocket was launched. This time, the mission was a success. The rocket injected a small satellite, Rohini-I, into orbit at a speed of 7.79 km a second at a height of 300 km. Rohini-I was in orbit for two years, tracked by Indian ground stations. It eventually completed 10,000 orbits of the Earth.

The successful mission was followed by the first development model called SLV-D1 in 1981. For the first time, data were received on an on-line computer from the satellite, instead of through a ground telemetry station. The rocket also carried the first

Indian-built inertial measuring unit to steer it steadily. Though the thrust and the burn time of all the four stages were better than the predicted values, the second stage showed an unplanned, slow spin. Subsequent analysis revealed that one of the four fins of the first stage motor did not respond to the commands from the onboard autopilot.

A confident team of rocket designers proceeded to correct the defect and try out many complex techniques. Accordingly, they increased the capacity of the SLV-3 by adding two strap-on motors to the first stage, each of which was equivalent to the first stage of SLV-3. An improved navigation and guidance system was designed and added.

In 1987 the first ASLV failed in its mission to place a satellite in orbit. The first stage motor itself did not ignite. Several modifications were made to the second ASLV. But ASLV-2 also failed (1988). The strap-on motors burnt out two seconds earlier than recorded during tests. The autopilot could not correct the impact.

The problems that led to the failure were identified and corrected in subsequent missions. The aerodynamic stability of the rocket was improved. A better propellant was used. The vehicle structure was strengthened. Hundreds of tests evaluated each and every part. The third development launch of ASLV in 1992 placed a satellite (SROSS-C) in orbit.

The modified ASLV-D4 in 1994 was perfect. The onboard computer guidance system compared the attitude, velocity and orientation of the rocket every second and computed the correction needed to reach the target. There was indeed some over-performance. The data on the fourth stage were available in real time at the launch base. Several new technologies were successfully introduced : strap-on motors, inertial navigation and guidance and real time decision-making.

It was time to go ahead with the plan to include liquid propellant engines for some stages of the rocket.

Polar Satellite Launch Vehicle

The aim was to develop a polar satellite launch vehicle (PSLV), designed to place a remote sensing satellite weighing typically 1200 kg in a 817-km polar sunsynchronous orbit. The rocket has a lift-off weight of about 294 tonnes and measures 44 m in height.

A PSLV has four stages : the first (2.8 m diameter) has a solid booster (rated as the third largest in the world), with six strap-on solid motors; the second stage has a liquid propellant engine; the third has another solid propellant engine, and the fourth is again powered by liquid propellants. The fourth stage liquid engines are pressure-fed, unlike the pump-fed engine in the second stage. In the fourth stage engine, helium gas stored under high pressure is used to push the propellants into the combustion chamber. Each stage has its own control system.

The first stage has 138t of solid propellant with six solid propellant strap-on motors each weighing 9t. The second stage carries 40.6t of liquid propellants. The third takes 7.2t o solid propellant, while the fourth takes 2t o liquid propellents.

The first stage takes the rocket to an altitude of 56 km, the second to 250 km, th third to 400 km and the fourth to the orbital altitude of 904 km.

The first development flight of PSLV was attempted in 1993. The lift-off was normal. But the second stage could not attain the expected velocity. As a result, the desired orbit was not reached. The failure was traced to a wrong reading of a control signal in the onboard guidance and control system. However, several other subsystems were validated: two liquid stages were flight tested; the guidance system performed well; onboard computers provided navigation, guidance and control; the solid first stage with six strap-on motors worked well; and the heat shield was jettisoned as planned.

Each failure gave the engineers some scope for improvement. All the stages were tested extensively. A simulated altitude performance test was conducted. The fourth stage which had indigenous twin liquid engines, was tested. The modifications suggested were incorporated into PSLV-D2.

PSLV-D2, launched in 1994, was a complete success. The satellite, IRS-P2, was placed in a polar sunsynchronous orbit at 817 km at an inclination (to the equator) of 98.6° as against the planned 98.7°. The satellite was controlled by the Telemetry, Tracking and Command Network in Bangalore, Lucknow and Mauritius. The mission marked a milestone in the country's space programme.

The next PSLV mission (PSLV-D3) in 1996 also went off perfectly. The rocket followed the pre-set trajectory and placed a 922 kg remote sensing satellite, IRS-P3 into a polar sunsynchronous orbit. Nevertheless, several improvements were made, including the introduction of wind-biased trajectory to reduce the effective load on the rocket during its ascent through the atmosphere.

The next mission marked the first operational flight of PSLV (also called PSLV-C1). Launched in 1997, it put IRS-1D into a polar sunsynchronous orbit. However, the satellite was placed at a lower perigee than planned (301 km, which was lower by about 500 km). Raising the perigee meant increasing the orbital velocity to the ideal of 7.444 km a second, as the velocity attained was less by 14 metres. Based on complex and patient calculations, the onboard rockets were fired several times over 10 days to restore the satellite to 737 km, which was acceptable.

PSLV-C1 was otherwise more than normal. The satellite it carried weighed 1200 kg as against 920 kg in the previous mission. The second stage liquid propulsion system was an improved version of the stages flown in the previous mission.

Post-flight analysis showed that the fourth stage of PSLV-C1 performed less satisfactorily because the pressure regulation system malfunctioned. Corrective action was taken for the next PSLV.

PSLV-C2 successfully put into orbit IRS-P4, known as Oceansat, as well as two foreign satellites viz., one from South Korea (KITSAT-3) and the other from Germany (DLR-TUBSAT). The rocket weighed 294 tonnes. The mission indicated the possibility of offering launch services to other countries for their satellites on a commerical basis.

Even as the rockets were perfected. satellites were designed to monitor the rockets and study other applications. A satellite series, Rohini, was started. Rohini-I was launched by SLV-3 in 1980. Though the satellite was designed to monitor the fourth stage of the rocket, it was in orbit until 1981. The indigenous solar panels worked well Rohini-II (RS-D1) was launched in the first development mission of SLV-3 in 1981.

Another series of satellites, designed mainly for technological or application missions was launched. Called Stretched Rohini Satellite Series (SROSS), the first two could not be put into orbit because of failure of the rockets. SROSS-C, launched by ASLV-D3, was placed in orbit (1992). It had two payloads, one for measuring gamma ray bursts and the other for studying the ionosphere over equatorial and low latitudes Another satellite (SROSS-C2), launched by ASLV-D4 (1994) carried the first indigenou nickel-cadmium batteries. The capability to design and fabricate Earth-orbiting satellite would be useful in view of the growin demand for launching small satellites.

Geosynchronous Satellite Launch Vehicle

Satellites in the geosynchronous orbit are necessary for any nation to provide reliable communications, countrywide television and data transmission, besides timely weather forecasts. India has relied on foreign rockets to launch its geostationary satellites, even as the country is nearing its goal of developing its own geostationary SLV (GSLV), which is quite a complex technological undertaking. Only five countries in the world (the United States, Russia, France, Japan and China) have the technology to make cryogenic engines (high-energy propulsion systems), needed for GSLV rockets.

The first stage of the GSLV has a booster with 129 tonnes of solid propellant. It has four liquid propellant strap-ons (with 40 tonnes of propellants each) instead of the six solid propellant strap-ons (10t each). The liquid second stage (37.5 t) is the same as in a PSLV. There would, however, be a new third stage, instead of the third and fourth stages of the PSLV. The third stage engine (with 12.5 t of propellants) providing a thrust of 7.5 tonnes) will be based on cryogenic fuels, (which remain liquid only at very low temperatures). The cryogenic engine will be restartable. It will use liquid hydrogen and liquid oxygen to provide the needed thrust to the GSLV.

Handling cryogenic propellant is a big challenge. Hydrogen is used in a gaseous state, while the oxidiser is in liquid form. The turbo pump in the engine needs complex thermal management as it handles gas at above 900Kelvin as well as liquid hydrogen at 20Kelvin. Any small leak will cause explosions. The engine requires complicated rotor dynamics with high-speed pumps.

Initially, the GSLVs will have Russian cryogenic engines supplied on a commercia basis. Meanwhile, an indigenous cryo engine and a stage are being developed . The engine will have the same specifications as the Russian engine. The first indigenous engine had been evaluated at the test facilities se up at Mahandragiri in Tamil Nadu.

The GSLV is designed to launch a 2000 2500 kg satellite into the geosynchronou transfer orbit. The experimental satellite carried by the rocket, GSAT, with six transponders (electronic devices that receive and transmit the signals) weighed 1540 kg. GSAT was designed to evaluate new technologies.

The First Flight of GSLV

The first developmental test flight of GSLV on March 28, 2001 at Sriharikota was aborted by the on-board computer one second before the lift-off. ISRO's automatic launch sequence system halted the lift-off after sensing that the thrust developed by one of the four strap-on liquid motors attached to the first stage was inadequate. The strap-on boosters were ignited 4.6 seconds before the main stage was to be ignited. After 3 seconds, the computer halted the sequence and saved the main rocket. The ground control and safety systems worked well.

After replacing the defective strap-on engine, the GSLV was relaunched on April, 18, 2001. The flight was successful. The main mission was achieved : the rocket injected the satellite, GSAT-I into the geosynchronous transfer orbit. However, the injection velocity was 99.4 per cent of the intended 10.2 km/second, resulting in a reduced apogee. The orbit reached was 181 km by 32,051 km instead of 180 km by 35,951 km, with an inclination of 19.2° to the equator instead of 19°. The shortfall was almost corrected over the next few days by firing the onboard thrusters. The orbit was raised to 33,806 km by 35,665 km (apogee) with an inclination of 0.997°. However, propellant consumption was more than expected because it was also used to correct an unexpected tilt of the two propellent tanks following an imbalanced flow of propellants. There was a shortage of 10 kg of propellant to achieve the correct orbit. Hence the satellite went into a drift orbit, with an orbital period of 23 hours and two minutes instead of 24 hours Nevertheless, several techniques were successfully evaluated including the use of new sensors and thrusters.

GSLV-D1 fulfilled all its objectives. Its success is significant, as failures in rocket launchings are quite common. The world's most popular commercial launcher, Ariane-

5 exploded in its first qualification flight in 1996. In 1997 the rocket's cryogenic engine burnt out prematurely. In 1998 one of America's biggest boosters, Titan 4A - Centaure failed, following a battery malfunction for a fraction of a second.

The hold at Sriharikota prompted comments on the very rationale of GSLV. It is pointed out that India needs self-reliance on its capacity to reach the geosynchronous orbit, since INSATs have become part of the nation's daily life and business and the nation cannot be constrained by any geopolitical development in the future.

Some self-styled experts have argued that PSLVs are good enough even to reach the geosynchronous orbit, little realising that they can lift only about 1500 kg. And the trend is towards heavier satellites in that orbit. That calls for stronger rockets with cryogenic engines that alone would impart the needed thrust (10.2 km a second) to achieve the orbit.

Once GSLV is operationalised, various rocket combinations are possible. For example, a rocket can place six or seven satellites in the lower Earth orbit (about 80 km from the Earth) or two one-tonn satellites in the intermediate orbit (som 10,000 km away from the Earth). Moreove the payload of a GSLV can be increased t 2000 - 2500 kg. as against the test satellit GSAT-I which weighed only 1540 kg.

Efforts are on to perfect the indigenou cryogenic engine even as the initial flight use the Russian engines for the third stag Even developed countries have taken decade to make the cryogenic engine an India has made serious efforts only since th mid-1990s. The first test of a model engin though ended prematurely, had perform to specifications and the data from the te have given the needed confidence to ahead. The cryo engine is expected by 200 and the stage to support it some 18 mont later.

Though the beginner's luck has evade ISRO in its maiden ventures in rocketry, it scientists and engineers have always com back to achieve the targets. Even if a batt or two are lost, the war is won!

6

UNDERSTANDING THE ORBITS

The young scientists in Thumba realised the significance of a revolutionary idea proposed in 1945 by the famous science writer, Arthur C. Clarke. He had suggested that radio signals from a satellite from the geostationary orbit could cover one-third of the Earth. The scientists were fascinated by the potential use of the orbit. Arthur Clarke, while on a visit to India, envisaged a bright future for a space programme in India.

Orbital dynamics is a demanding science. It is amazing how Indian young men and women have mastered the science, leaping ahead from the well-known fundamental facts and theories to the nuances of accurate positioning of satellites in orbits.

The daily rotation of the Earth (measured with reference to stars instead of the sun) takes 23 hours, 56 minutes and 4 seconds. A satellite in the geosynchronous orbit (GEO) at about 36,000 km above the equator also takes almost the same time to complete one orbit of the Earth. A satellite placed in such an orbit at a velocity of 11,088 km an hour would synchronise with the rotation of the Earth on its axis at 1674 km an hour at the equator. Three satellites, placed 120 degrees apart, can be accessed from almost all parts of the Earth.

The challenge of placing a satellite in the GEO is formidable. The most efficient way of attaining GEO is through the geostationary transfer orbit (GTO) nearer the Earth. The latter is oval-shaped, with a perigee (nearest point to the Earth) of about 250 km from the Earth and an apogee (farthest point) of about 35,900 km. When a satellite is in the oval orbit, a rocket on board is fired to circularise the orbit. The rocket called apogee rocket, is usually fired thrice in as many oval-shaped orbits. Once the satellite is in GEO, it is allowed to drif towards its alloted location over a predetermined longitude.

As the Earth's spin axis is inclined at 23.5 to the ecliptic (the plane enclosing the Sun and the Earth), the GEO is in sight of th sun most of the year. However, at equinoxes the satellite goes into the Earth's shadow when onboard batteries would supply powe

Maintaining a satellite in the GEO is also a complex challenge. The Earth's shape (an oblate spheroid rather than a sphere) affects the satellite; the polar radius is some 21 km shorter than the average equatorial radius. The equatorial cross-section is an ellipse rather than a circle; hence a GEO satellite tends to drift over time. The Earth's mass is not distributed evenly around the equator. Moreover, the sun and the moon exert their pull on the satellite. Furthermore, the charged particles from the sun, called the solar wind as well as the magnetic field in space can disrupt a satellite in the GEO. As a result, a satellite in the GEO would drift in the east-west and north-south directions, if not periodically corrected.

The correction is done by various ingenious techniques. Reaction wheels on board a satellite are rotated at about 2,500 revolutions per minute to impart stability. Satellites in the GEO have in addition, momentum wheels.INSAT-3B, for example, has momentum wheels for all its three axes, that rotate at about 3,500 revolutions per minute. When the wheels cannot make the correction, reaction control thrusters on the satellite are fired to correct the deviation.

A satellite typically has an Earth sensor, a sun sensor and a star sensor to help locate its position in the orbit. The Earth horizon sensor detects the natural infrared radiation of the Earth. The sensor is designed to reject other types of radiation (e.g. from the sun or the moon). The sun sensor measures the sun angle with reference to the satellite. Star sensors provide the most accurate reference. In addition, satellites have gyroscopes, particularly those in the lower orbits.

The stability and the pointing accuracy of the country's satellites are quite remarkable. A satellite can spin like a top and remain stable or it can have three-axis stability. All movements of a satellite can be described as rotations about one or more of its three axes viz., the roll axis along the direction of its motion, the pitch axis in its up and down direction perpendicular to the roll axis and the yaw axis which is perpendicular to the other two axes.

An INSAT satellite typically maintains a pointing accuracy of plus or minus 0.2° in the pitch and roll axes and about 0.4° in the yaw axis. Nearer the Earth, an IRS satellite typically maintains an orbit with an accuracy of 0.15°.

Another type of orbit has been found useful for monitoring and imaging the Earth's natural resources. It is called sunsynchronous polar orbit, near the Earth around 700-1000 km. The plane of that orbit makes the same angle with the sun-Earth line as the Earth goes around the sun.

The plane of the orbit in fact rotates at about one degree a day, which coincides with the rate of rotation of the Earth around the sun. This is possible because of the equatorial bulge of the Earth (its radius at the equator being 6378.14 km as against 6356.79 km at the poles). The bulge pushes the plane of a satellite's orbit to the east, provided the satellite crosses the equator from the southern to the northern hemisphere in a westerly direction. A sunsynchronous satellite passes over a given latitude at the same local time, provided it maintains a given height and its inclination. An advantage of this feature is that the satellite's cameras can register images of the ground below at the same angle in successive orbits. Comparison of the images taken on different dates therefore becomes realistic. For example, IRS-1C at an altitude of 817 km with an inclination of 98.69°, crosses the equator at 10.30 a.m. completing an orbit in 101.35 minutes, while Oceansat at a height of 720 km and inclined at 98.28° crosses the equator at 12 noon and completes an orbit in 99.31 minutes.

A satellite in the sunsynchronous orbit needs constant monitoring and periodic control to keep it stable. The satellite has Earth sensors that capture the temperature variation between the warm Earth and cold space. Sun sensors are used to measure the accuracy of the orbit with reference to the centre of the sun. A more accurate measurement is made by a star sensor, which tracks stars and compares its position with given data. Gyroscopes are also used for measuring the yaw axis. Ths IRS series has three-axis body-stablised system using reaction wheels, magnetic torquers and hydrazine thrusters.

IRS-1C can visit the same place once every five days, whereas the Oceansat is designed to revisit every two days.

7

WORLD CLASS RESOURCE SATELLITES

In the mid-seventies, the industrial estate in Peenya, a suburb of Bangalore, was in its early phase of development. Inside some of the humid worksheds in the area, an unusual project was taking shape. A team of 200 scientists and engineers designed an object, quasi-spherical in shape with 26 flat faces, 1.6 m across and 1.2 m high. Weighing 360 kg, it had special paints to keep the internal temperature within the range of 0°C-40°C, though the outside temperature varied from 100°C to minus 60°C. It was India's first satellite designed to be in low-Earth orbit. It was called Aryabhata, after the famous astronomer.

Several models of the satellite were fabricated. A test chamber to simulate the extreme vacuum and temperature in space (plus 100°C to minus 100°C) was established to evaluate the models.

Many organisations in the country were involved in making the satellite. They include the Hindustan Aeronautics Ltd., the Bharat Electronics and Radar Development Establishment, besides the Indian Institute of Science and several private companies.

As there was no indigenous rocket suitable for purpose, it was decided to launch Aryabhata from Russia. The Russians also provided batteries, the spin system and tape recorders, as indigenous components were not yet ready.

In April 1975 a Russian rocket inserted Aryabhata into a circular orbit of 594 km at an inclination of 50.40° to the equator. Aryabhata orbited the Earth once every 96.41 minutes. The satellite's orientation could be measured with an accuracy of 1° as against the original requirement of 2° to 2.5° The speed (nominally about 8 km a second was estimated within 20 metres a second.

Designed for an active life of only six months, Aryabhata continued in good shape The flow of data went on until April 1980 This boosted the morale of the scientists Even the world's first satellite, Sputnik-1 transmitted only for 21 days.

A section of the Press, however, called the mission a failure. It pointed out the disruption of power supply to scientific experiments after the first 50 orbits, though the power system itself worked normally. The experiments had piggy-backed extra devices, not being the main objective of the mission. But some people ignored the positive side.

Aryabhata continued in orbit even after it stopped sending data in 1980. Tracking was intensified as it approached its end. The re-entry of the satellite into the atmosphere on February 7, 1992 was remarkably close to the prediction made by the scientists.

The main ground station was set up in Sriharikota. One of the newly built antennas received the signal even when the satellite was 2,500 km away. Its velocity was ascertained by measuring the change in the frequency of the signals from the satellites as recorded at the receiving station, when it moved across the sky. The distance of the satellite and its angle were calculated accurately. Indian engineers were in full command of the satellite from the beginning.

In fact, the Bears Lake Station near Moscow was set up by Indian engineers.

Following the success of Aryabhata, a more sophisticated satellite was designed and developed. It was named Bhaskara, after a leading Indian astronomer of the 6th century A.D. and another eminent mathematician of the 12th century.

Bhaskara was launched from Russia in 1979. The satellite could take 200 different commands as aganist 35 by Aryabhata. The data flow from Bhaskara was 91,000 bits per second as against 2560 bits per second from Aryabhata. The Sriharikota range received the data when the satellite crossed over the range.

The two-channel camera on board Bhaskara could not be turned on initially but simulation on the ground gave the controllers confidence to make it work. The satellite continued in orbit for about two years until 1981 and covered the country thrice in imageries.

Bhaskara-2 followed in 1981. It too had a TV camera. The satellite had indigenous thermal coatings, solar cells and panels. It completed ten years in orbit, far beyond its planned lifetime.

Even as the resource satellites were perfected, a group of scientists began remote sensing experiments with a programme to detect the coconut wilt disease in Kerala with airborne cameras. In 1974 an inventory of crops and crop acreage estimation were attempted based on airborne photographs. In 1976 balloons with cameras were sent upto a height of 27 km. It was realised that a balloon's trajectory could not be controlled. By then, the United States had launched the first satellite for land observations from a height of 900 km. ISRO engineers were quick to realise that satellites with payloads for remote sensing could be developed in India itself.

A satellite remote sensing programme was approved by the Government in 1982, when Bhaskara was giving encouraging results in its remote sensing mission.

The design chosen for the satellite payload was an improvement over the US model in its LANDSAT series. Instead of the electromechanical scanners of the LANDSATs, a new technique known as the push-broom method was chosen. In the new method, the satellite's movement around the Earth itself could register the image corresponding to the field of view (with a resolution of 36 metres and 72 metres on the ground). Images in four bands of the electromagnetic spectrum were registered in multispectral cameras.

The electromagnetic spectrum was studied in detail for the remote sensing missions.

The colours in a rainbow indicate the visible portion of the electromagnetic spectrum, which is an array of electromagnetic radiations arranged according to frequency and wavelength. The spectrum has various regions ranging from short gamma rays to long radio waves. The optical window (which shows the colours in a rainbow) is narrow, ranging from blue (0.4 micrometre in wavelength) to red (0.7 micrometre). Just beyond the red end is the infrared region, which is subdivided to indicate near, middle and thermal infrared radiation. The visible and infrared remote sensing sensors provide information on the chemical properties of a target. Thermal infrared remote sensing indicates the thermal properties of objects, whereas microwaves show the physical characteristics of objects.

Another innovative practice adopted was the use of charge-coupled devices (CCD) for producing images. CCDs convert optical, infrared and ultraviolet images into electrical current. Unlike a photographic plate, which records only 1 or 2 per cent of the light that reaches it, CCDs can detect nearly every photon of light. Hence, better images are generated.

The IRS Series

IRS–1A and an identical IRS–1B were launched from Russia in 1988 and 1991, respectively. Both were in polar, sunsynchronous orbit, each with an accuracy of 1 km in orbit determination. The accuracy was achieved by the attitude and orbit control which had infrared horizon sensors, sun sensors, a gyroscope and a star sensor.

The second generation satellites for remote sensing, IRS–1C and IRS–1D, were launched in 1995 and 1997, respectively. IRS– 1C was designed for a global mission; its data were made available to users in various parts of the world. The satellites have enhanced capabilities compared with IRS–1A/B in terms of spatial resolution, spectral bands and revisit capability. Onboard recording was also done. Its panchromatic (PAN) camera gave the highest spatial resolution (5.6 metres) offered by any civilian satellite in orbit until IKONOS was launched in 1999 by a US company providing images of one metre resolution. Optics for IRS–1A/B was obtained form a French firm. Indigenous development of optical elements was taken up for IRS–1C.

The 5.8 m resolution of IRS–1C's images has been found useful by many countries in the world. ISRO set up a marketing wing ANTRIX to promote its products and services to foreign countries. Contracts were signed with many countries for downloading the IRS imageries.

IRS–1C has many technological improvements. A steering mechanism on board moved the pan camera 26° and thereby it is possible to revisit an area once every five days and get stereo pairs of imageries. The swath (the path covered by the satellite) of the pan camera is 70 km. Its sharp resolution (5.6 m) is useful in cartography and urban planning. The multispectral sensors have a swath of 145 km and a resolution of 25m. It is useful for agricultural applications, land use planning and water resource monitoring. The third sensor on board called Wide Field Sensor (WiFS) has a broad swath of 804 km and a coarse resolution of 188 m. It is used for vegetation monitoring.

Technological Mastery

India's technological mastery in satellite orbit control was dramatically demonstrated in the IRS–1D mission. PSLV–C1, which launched the satellite in 1997, did not place it in the desired circular orbit of 817 km. Instead, the orbit was elliptical with its apogee (farthest point from the Earth) at 821 km and perigee (the nearest point from the Earth) at 301 km. The orbit had to be corrected and the orbital velocity achieved was less by 140 m a second as against the ideal of 7.446 km a second. The thrusters on board were fired after a careful calculation over ten days, when the satellite was visible over India. As a result, the perigee was raised to 737 km with the apogee remaining at 821 km. The orbit was acceptable, and IRS-1D continued to function beyond its design life of three years. Considering the complexity involved in the operation, the success achieved is an eloquent testimony to the skills of the ground controllers.

Ground controllers took precautions during the Leonid meteor showers in 1998, when dust particles from meteor storms were expected to damage satellites. The controllers rotated the solar panels of the satellites, and shut off cameras and transponders for a while. However, the showers were not as severe as predicted.

The first developmental launch of PSLV in 1993 could not place the satellite, IRS–1E in orbit. However, the second and third developmental launches of PSLV (in 1994 and 1996) successfully placed IRS–P2 and IRS–P3, respectively into orbit. The first and second operational launches of PSLV repeated the success in 1997 and 1999 by placing IRS–1D and IRS–P4 (Oceansat), respectively, into the planned orbits.

Oceansat goes round the Earth every 103 minutes covering the same point in India every two days. It has two sensors, a multi-frequency scanning microwave radiometer and a ocean colour monitor (OCM). The radiometer collects data on sea surface temperature, wind speed, water vapour in the atmosphere, cloud water content, ocean currents and pollution as well as shoreline changes. The ocean colour monitor detects sea temperature through the colour of the sea, tracks phytoplankton (minute organisms that support marine life), chlorophyll concentration, sediments in the water and atmospheric aerosols. The data would be useful in locating potential fishing areas, oil, minerals and coral deposits in the sea. Forecasts of fish concentration would be faxed to about 60 centres in the country for the benefit of fishermen. The ocean data would be validated by observations made by ships and buoys. OCM is also useful in assessing the state of vegetation on land.

The satellite is monitored and commanded by the ISTRAC Spacecraft control Centre in Bangalore. The satellite has a recording facility to keep the data acquired outside the visibility area of the Indian satellite station. The entire Earth is covered in 29 paths (north-south lines) and 30 rows (east-west lines). India lies in paths 8–11 and rows 9–13. The National Remote Sensing Agency (NRSA), Hyderabad receives the data from the satellite.

NRSA has the latest equipment to process the satellite data. It generates data products, both digital and photographic. The data are made available in computer compatible tapes. The raw data are corrected and provided according to the specified sensor, path, row and date of the pass of the satellite. Several images of the same area of interest are overlaid to get a digital mosaic product.

Satellite data are presented in infrared film, as vegetation generally reflects energy in infrared not visible to the human eye. Colour infrared film can record the energy because it is sensitised to green, red and near infrared, instead of blue, green and red wavelengths of ordinary colour films. Healthy vegetation is seen in colour infrared film as bright red or pink area, while dead or dying vegetation is given a shade of green. Thus it is called false colour infrared technique, in which the colours are shifted towards the longer wavelengths. Blue is generally dropped; green is assigned blue, red is shown as green and near-infrared is indicated as red.

Data registered from different regions of the electromagnetic spectrum can be merged with radar data and processed, thereby combining the advantages of both types of sensors. While radar can penetrate clouds, the visible and infrared channels discriminate the features clearly.

The IRS missions are supported by ISRO stations in Lucknow, Mauritius and Bearslake (Russia).

8

NEED AGAINST GREED

Satellites have confirmed the wise observation of Gandhiji that Nature has enough to provide for everyone's need but not to everyone's greed. The meaning of sustainable development could not have been better articulated. And resource satellites have dramatically proved the Mahatma right.

Even before the first satellite image of the Earth was available, the noted British astronomer, Fred Hoyle, predicted that once a photograph of the Earth taken from outside is available, a new idea as powerful as any in history would be let loose. The new idea is now articulated as the renewed concern to preserve the Earth from being destroyed by human greed and violence. The 'blue jewel' floating in the eternal silence, as seen and photographed by astronauts and cameras on board satellites, has led to a worldwide realisation that our planet is unique and is therefore worthy of preservation. A new dawn of humility and respect for Nature have led to green movements to preserve the world's biodiversity and safeguard the intricate web of interdependence of plant, animal and human life on one another.

Nowhere is the relevance of space technology to the preservation of the Earth's beauty, diversity and interdependence is demonstrated as clearly as in the applications of remote sensing satellite data.

A major application area is agriculture, especially the pre-harvest crop acreage and production estimates of major crops viz., rice, wheat, sorghum, cotton, mustard and groundnut in 15 states. The forecast includes district-level production estimate, useful for planning foodgrain storage and distribution.

A general application of remote sensing data is the determination of vegetative biomass using the near-infrared and visible bands. Based on the data, it is possible to indicate drought conditions and the change in the vegetation density.

Increased cultivation of high-yielding irrigated rice varieties has attracted pests such as the brown plant hopper. Similarly, changes are detected in the wheat crop hit by the yellow rust epidemic. Changes in the spectral reflectance and emission from the crops are studied to identify the crop type and the pest. A desert locust forecastng system has been developed for use in Rajasthan, Gujarat and Haryana.

India has about 12 per cent of good forest cover as against the required 33 per cent. In 1986 satellite imagery showed a decline in the area under forests. The finding led to several conservation measures. The forest maps are now revised every two years mostly on the basis of satellite data.

Scientific management of forests, based on satellite data, is essential for the preservation of the country's forest wealth. A pilot study is under way in Madhya Pradesh under which stock maps of the forests have been generated. It would be studied along with infrastructure maps, drainage and watershed maps as well as elevation maps. Estimation of tree volume from satellite data is also being developed.

Satellite data are used for monitoring forest fires, deforestation and afforestation.

Special maps on specific topics (such as depicting tiger reserves) are also prepared.

Under the ISRO Geosphere Biosphere Programme, a biodiversity study was started in Central Himalaya, which would, among others, examine the relationship between biodiversity and biophysical and environmental variables. In North Bengal, elephant corridor mapping has been carried out. Three major elephant routes have been identified.

The loss of storage capacity of several major reservoirs has been traced to soil erosion in the watersheds serving as their catchment areas. The soil loss is evaluated and the reasons (such as deforestation) identified for initiating remedial action.

Irrigation systems are best evaluated by satellites. The cropping pattern and crop yield in the command areas are detected for this purpose. The performance of 14 selected command areas across the country has been monitored. Satellite data can reveal the mismatch between water release and water requirements. Erosion of river banks, flood monitoring and mapping, and study of cyclone-hit areas are taken up regularly. Coastal land use and shoreline changes have been monitored for several States. Mangroves and coral reef zones have also been studied. It is pointed out that the damage done by the Orissa super cyclone in 1999 would have been reduced, if only coastal mangroves in the State had been preserved instead of being converted into fish ponds catering to commercial interests.

For the last five years, the snow-melt run-off from the Sutlej river basin into the Bhakra reservoir during summer has been correctly forecast, based on monitoring the snow in the Himalayas. The forecast is accurate to one per cent of the actual flow. The forecast, issued in April every year, has been useful for scheduling the Bhakra water for power generation and irrigation.

The extent of areas under cultivation has also been estimated for every State. Grassland mapping for three States has been done and base maps for each district prepared.

The Rajiv Gandhi National Drinking Water Mission is under implementation, based on satellite data. Ground water potential zone maps for 447 districts covering the entire country would be prepared. The success rate in locating underground water is 88-95 per cent as against 45-55 per cent in the conventional methods.

Salt-affected soils in over 20 million hectares have been identified in different parts of the country. Nearly 40 per cent of it is in the Indo-Gangetic plains of Punjab, Haryana, Rajasthan, Uttar Pradesh and Bihar.

A pilot project of significance to the entire country is being set up in Bangalore. Called Agro-climatic Planning and Information Bank, it would provide a variety of information (on seeds, fertilisers, plant protection chemicals and farm machinery) to farmers, along with weekly rainfall probabilities.

A drought assessment and management system has been designed and implented. In eleven States, crop and seasonal conditions were assessed and reports at the district level prepared for the Khariff season of 1998. The sytem would be expanded by using high-resolution data.

Other projects implemented give an idea of the wide scope for remote sensing data application. In Tamil Nadu, a project on estimating the acreage of banana orchards has been completed. Sugarcane mapping in Haryana and the Krishna valley was carried out.

Inventory and mapping of land use and land cover has been taken up for the whole country on a scale of 1 : 250 000, Areas under shifting cultivation were mapped on a scale of 1 : 50 000.

Wasteland development is a major programme for increasing the area under cultivation. A wasteland data base in digital format is being constructed for all the districts in India.

Satellite-based imagery of selected locations has been studied for correlation between ground reflectance and mineral presence. The Regional Remote Sensing Centre, Bangalore of the Department of Space has created a database for the study. Combining airborne information, the

Geological Survery of India compiles lineament and fault maps as well as gravity and aeromagnetic maps. The maps serve as guides for locating minerals.

The study of the oceans has been intensified with the launching of Oceansat. The ocean study envisages generation of sea surface temperature maps, forecasts of fisheries potential and collection of data on winds and waves. The payload of Oceansat has instruments for detection of wind speed and direction, wave height, sea surface temperature and ocean currents.

Satellite data have been found useful in archaeological studies. Unexplored sites of interest have been studied. The course of the now invisible Saraswati river has been traced from Manasarovar in Tibet to the Saurashtra coast in Gujarat.

Modern mapping is based on satellite images, but the resolution required for cartographic purposes is of the order of less than two meters. ISRO's Cartosat, (IRS-P5) is designed for mapping applications. It has two panchromatic cameras with 2.5m resolution and a swath of 30 km. Stereo images of the mapped terrain will also be possible.

Cartosat will be followed by a Resourcesat (IRS - P6) with improved cameras. Imageries in the visible and infrared portions of the electromagnetic spectrum are subject to a serious limitation viz., clouds that would obstruct the view of the sensors. Clouds are quite frequent in tropical countries, limiting the time available for imaging the areas. Hence, radar sensors are used to detect and measure microwave signals reflected from the surface of the Earth. Radar signals penetrate the cloud cover. Passive radars measure the radiation present in the atmosphere. Active radars send out their own signals. Multiple bands of radar are used for detecting different types of land cover.

Radar has several advantages. It can function regardless of clouds and haze. Radar can measure the roughness and conductivity of the ground water surface. Radar is useful for mapping soil moisture conditions under cloud cover. Water-deficit areas, seepage from canals and areas of water recharge could be identified. Radar images can also be combined with visible sensor data.

Using the microwave data from the European Remote Sensing Satellite (ERS), discrimination of rice and potato crops had been made in the Gangetic plains of West Bengal.

At the Grassroots Level

Satellite-derived data are applied at the grassroots level. Satellite data identify and describe the features and the status of natural resources. The data are integrated with conventional data (e.g. surveys) and socioeconomic data. The goal is utilisation of natural resources in a sustainable manner. People's efforts and expertise would help in implementing projects based on data analysis.

A computer-based information processing system merges satellite-derived data with tabular and cartographic data, analyses the impact of mixing selected data and provides a preview of possible decisions and their likely consequences. A system which processes the data in the manner described is called Geographic Information System (GIS).

A National Natural Resources Information System has been initiated in 30 selected districts. Remote Sensing Applications Centres have been set up in 23 States (as of March 1999) that will process satellite data with GIS packages. The State Centres, together with private entrepreneurs, universities and non-governmental organisations, participate in the Integrated Mission for Sustainable Development. Started in 1992, the Mission is designed to generate action plans suitable for specific locations, based on the availability of natural resources and the needs of the people. Such action plans have led to the construction of check dams, farm ponds, vegetation bunding, fodder and fuel wood plantations and horticulture and agroforestry activities. In the first phase of the Mission, 175 districts have been included. The level of people's participation in the projects has been encouraging.

The Indian Institute of Remote Sensing, Dehra Dun offers training in the field of remote sensing and allied areas. The Centre for Space Science and Technology Education in Asia and the Pacific (affiliated to the United Nations) in Dehra Dun also provides training in this field. Training programs at school, university and professional levels are provided by the Regional Remote Sensing Centres as well as the National Remote Sensing Agency, Hyderabad.

Indian remote sensing satellite imageries have impressed the overseas market. They are world class in quality. ISRO's commercial wing, ANTRIX Corporation Ltd., has contractual arrangements with EOSAT (an American Company) which markets the Indian imageries worldwide outside the Indian footprint area. The National Remote Sensing Agency, Hyderabad has retained the right of receiving the data stored on board the satellites. Only NRSA can receive the data from the footprint area comprising India and its neighbouring countries. ANTRIX has concluded agreements with several other countries including Germany, Japan, Australia and Thailand for providing access to IRS data in real time when an IRS is over their territory. Many European cities and landscapes appear in excellent detail in the IRS imageries.

9

THE INSAT SERIES

When the world's first commercial satellite, Early Bird, was launched in 1965, India too became virtually an "early bird" in the field of satellite communications. The experimental satellite Earth station for communications became operational in Ahmedabad in June 1967.

The 14-metre steerable antenna of the station could not, however, work with an American satellite. The fault was not on the ground but in space : the satellite did not reach the correct orbit. Still, video transmission capability of the Indian station was demonstrated. Some images from the station were received in Japan.

By then India had became a member of the International Telecommunications Satellite Organisation (INTELSAT) which started providing intercountry satellite links. India decided to have an earth station to work with Intelsat's Indian ocean satellite. The expertise available in Ahmedabad was found seful. The Department of Atomic Energy as given the task of constructing an earth ation (29.7 m diameter) in Arvi near Pune. rvi became operational in 1971. It is now nown as the Vikram Earth Station.

Arvi picked up traffic quickly. It was llowed by a remarkable experiment in atellite television ever undertaken in a eveloping country. In 1975 the Americans unched the first communication satellite hich had three-axis stability. It was called pplication Technology Satellite (ATS-6) and as lent to India for one year for its Satellite nstructional Television Experiment (SITE). t provided direct telecast to about 2400 ommunity receiving sets in as many villages n clusters of 400 each in six States. At that ime only five cities in India had television tations each of which had a range of 8 km. ITE was a major project as creating rogrammes for different educational and ocial levels was a big challenge. SITE proved hat satellite TV could work in India and howed the potential.

Meanwhile, INTELSAT increased the ower of its satellites, so that they can work with smaller ground stations. India took the opportunity to build 10-m dish antennas for domestic service with an INTELSAT satellite. The nucleus of a domestic satellite network was born. In fact, a plan for a telecommunication network was approved in 1977.

In a remarkable coincidence, a Franco-German satellite, Symphonie, was loaned to India in 1977 for experiments in telecommunications with a domestic satellite.

By then, some engineers in ISRO had more ambitious plans and decided to build a geosynchronous satellite !

Every aspect of the technology was totally new, including the most challenging three-axis stability of the satellite.

An opportunity to launch such a satellite was made available by the European Space Agency (ESA). They offered to take the Indian satellite in the test flight of ESA's Ariane rocket. The offer was accepted.

The Ariane rocket with the Indian satellite was launched in 1981. The project was called Ariane Passenger Payload Experiment or APPLE. For a developing country, it was an mbitious venture. An improvised fourth tage of SLV-3 rocket served as the apogee oost motor designed to circularise the oval-haped orbit of the satellite. APPLE was a eavy weight; it weighed 673 kg at lift-off.

Unfortunately, one of the two solar panels ailed to deploy. It led to several complications ut the scientists managed to correct every eviation except the solar panel. Still,almost ll subsystems including an indigenous omentum wheel were proved and several xperiments were conducted, including ewspaper facsimile transmission and an ntercity scientists' meeting. Even the partial ailure was converted into a success. The atellite was virtually turned into an orbital aboratory that helped Indian engineers face he challenge of building and working eosynchronous satellites for communication nd television.

Three-in-One Design

Indian experts decided to go in for a three-n-one satellite,while finalising the design of he domestic satellites in the INSAT series in order to provide telecommunication, television and weather services. The first two satellites (INSAT-1A and 1B) were built by a US company under contract as specified by India.

INSAT-1A was launched in April, 1982 by a US Delta rocket. The rocket placed the satellite into a transfer orbit. But a communication antenna did not open. It blocked four of the 12 thrusters on the satellite, which were needed for control. Corrective action depleted the fuel meant for keeping the satellite steady for seven years. The duration of TV broadcasts was reduced because the undeployed solar sail covered the surface of the satellite and led to a heat build-up. But efforts continued to work with the satellite. The communication antenna was eventually deployed. Communications, weather and data services were operated. Soon, other troubles followed during the eclipse season in August 1982. The sun was sometimes visible in one of the Earth sensors. The sensor was therefore shut off. It was later found that the other Earth sensor unexpectedly saw the full moon. The phenomenon was unpredicted. The lunar glare disabled the sensor. The satellite lost the Earth lock. But commands from the Earth did not work, and the fuels were depleted. The satellite soon disappeared.

INSAT-IB was launched in June 1983. But INSAT-1C, which was delayed by launch vehicle failures, was sent up only in July 1988. Shortly after launch, the satellite suffered a power short-circuit. It could be partly operated for 16 months, when it failed completely. The next satellite in the series, INSAT-1D, could be launched only in June 1990, as it had to be repaired following an accident on the launch pad. The silver lining in the cloud was provided by INSAT-IB which continued service until July 1990, when INSAT-D took over. In order to augment the services, some capacity was leased from ARABSAT and other satellites.

The Second Generation

The second generation of INSAT series was built in India itself, though launched by foreign rockets. The new series was needed to continue and expand the service provided by the INSAT-1 series and provide new services such as data and mobile communication. More earth stations linking remote areas were envisaged.

A new chapter opened with the launch of indigenous INSAT-2A and -2B satellites in 1992 and 1993, respectively. The payloads in the second generation satellites were heavier than the first. Several technologies were developed for the first time in the country including power amplifiers, antennas, momentum and reaction wheels, control systems, apogee motor and solar arrays.

INSAT-2A was placed at 74° east longitude; it is now in an inclined orbit, used for some VSAT services. The services of INSAT-2B, were discontinued in 2000.

The next two satellites in the series, INSAT-2C and -2D were designed without the weather monitoring system, as adequate provision for the service was already available in the satellites in orbit. Without the meteorogical payload, the new satellites could have their solar panels on both sides.

INSAT-2C was launched by an Ariane rocket from Kourou in December 1995. Within a few minutes of its injection into the orbit, the Master Control Facility (MCF) in Hassan in Karnataka took charge of the satellite. After a successful firing of the apogee rocket, MCF allowed the satellite to drift to its location viz., 93.5° East longitude, where it was collocated with INSAT-2B. In a unique mode of deployment, the two INSATs were collocated in the geostationary orbit in order to gain the benefit of a single large satellite

INSAT-2C has four new features : higher frequencies in the so-called Ku band (11-14 GHz) to cater to a large number of very small aperture terminals, a larger 'footprint' to extend the coverage from West Asia to South East Asia; mobile communication from the geosynchronous orbit; and a stronger signal. The satellite can better withstand solar radiation. INSAT-2C was designed to provide another service viz., mobile communication on an experimental basis. Two types of mobile services were demonstrated. One refers to a mini voice or data communication terminal of the size of a briefcase and another, a smaller terminal resembling a lunch box. The design is being modified to include the facility of contacting the geographical positioning system (GPS) satellites for knowing one's exact location on the ground.

Some international companies have launched small but sophisticated satellites in lower Earth orbits to work with hand-held mobile phones. The orbits are far below the geosynchronous orbit. Some observers wonder whether India's choice of the geosynchronous orbit for mobile services is in line with modern trends. It is pointed out that India needs a domestic mobile service, which meets the country's main requirement. Those who need international mobile links thorugh hand-held devices could easily avail themselves of the foreign systems available in the country. Moreover, mobile communication services are provided from the geosynchronous orbit in other countries too.

The next satellite, INSAT-2D failed after functioning for a while in orbit. The fourth indigenous communications satellite was injected into orbit in June 1997. But after four months, INSAT-2D was given up in

October 1997, as it became inoperable. Basically, there was a power problem, which reduced the power available to the satellite to one-fourth of the designed capacity. Moreover, one of the satellite's solar arrays could not be rotated to track the sun. As many heaters did not work, the fuel lines froze and the control rockets could not be operated.

Experts described the failure as a random event. They pointed out that such failures occurred in many foreign missions. For example, NOAA-13, LANDSAT-6, TELSTAR-2 and a Japanese H-II failed shortly after launch.

The services from INSAT-2D were transferred to other INSAT satellites. The failure occurred when INSAT-2A could not maintain its position precisely, because of insufficient fuel on board for operating its control rockets. The US-built INSAT-1D, launched in 1990, also neared its end. Moreover, some of the Japanese transponders on INSAT-2B and 2C failed.

In order to meet urgent needs, India purchased ARABSAT and moved it to a new location, renaming it as INSAT-2DT. Some capacity of Thaicom-3 was also leased.

The success of INSAT-2E, launched in April 1999, came as a big relief. The satellite has eleven transponders, which can provide 12,000 two-way voice links or broadcast about 100 TV channels (in a compressed format) or a mix of both. The satellite is parked over 83° east longitude. Five transponders are designed to provide a zonal beam that covers most of South-east Asia, West Asia and China. The other transponders focus on a wide beam covering the area from Central Europe to Australia. The satellite also carries an advanced meteorological payload.

INSAT-2E is the first Indian satellite utilised by an international organisation. The worldwide satellite service provider, INTELSAT, has leased eleven transponders from the satellite. The deal is a recognition of India's technological progress. All the transponders taken by INTELSAT were utilised quickly. Several Indian TV companies (e.g. SUN TV, Asianet, E-Nadu and Vijay TV) have switched over to the new satellite. The signal received in India from INSAT-2E is twice stronger than that from the current INTELSAT satellites in the Region.

The satellite is expected to function for 13 years, provided the onboard fuel meant for ensuring its stability lasts that long. There is about 400 kg of the required fuel after the satellite was parked in the allotted place.

Meanwhile, the design of the third generation INSATs was finalised. Five satellites (INSAT-3A to 3E) were planned.

The launch of INSAT-3B was taken up first in order to meet the shortage of capacity in some of the communication bands following the loss of INSAT-2D. INSAT-3B will be followed by 3A and 3C satellites. Its successors are likely to provide improved weather services and direct-to-home TV and other applications that need higher power on board.

INSAT-3B is primarily intended for business communication, developmental communication and mobile services. The satellite can support portable terminals and transmit voice, fax or data. Certain communication frequencies (Ku-band) used for the first time would permit the operation of smaller ground terminals.

INSAT-3B is located as 83° East longitude along with INSAT-2E. INSAT-1D and -2A are collocated at 74°E longitude, while INSAT-2DT is at 55° E longitude.

10

A TECHNOLOGY FOR THE NEW MILLENNIUM ?

The invention of the printing press and moveable type in the 15th century changed the world forever by spreading new ideas in science, religion, government and economics. Today, the Internet is well set to equal the role of the printing press in bringing about new ways of learning, communicating and doing business.

Satellites as well as the Internet are facilitated by digital technology. Information of all types (e.g. text, photographs, audio, movie films) is converted into a digital format (a binary code consisting of a series of zeros and ones). Once the information is in the digital form, it becomes simpler to transmit and distribute it regardless of the medium. Digital technology thus allows the transmission and switching of large volumes of varied data in multimedia (text, sound, video) in the same format at a lower cost and in a very fast manner. A modern communication satellite can, for example, transmit in one second more than one gigabyte of information, equivalent of two or three times the *Mahabharata* and *Ramayana* epics combined! The benefits of data transmission of this order would only be limited by the telecommunication infrastructure available in a country as well as the regulations that govern it.

The demand for high-speed data communication is growing by leaps and bounds and will soon exceed that made by voice transmission. The growth of the Internet and the use of World Wide Web are pushing the demand for reliable communication links. The number of Internet users is expected to grow from about 180 million today to one billion by 2005. The users are going to need gigabits of transmission capacity not only for voice and data links but also for video and audio communication. The traditional telephone lines alone cannot handle the demand, even if optical fibre transmission lines are increased to serve heavy traffic centres. Satellites can play a crucial role in bringing about universal access to information.

A review of the intiatives taken in designing and operating India's domestic satellites (INSATs) in the geosynchronous orbit would show the way in which the technology has been developed and how the country has absorbed the technology.

Space offers several advantages in telecommunication services. A space link is ideal for remote and rural areas that do not have traditional communication links. The cost of connection does not depend on the distance of the link. Space links simplify connectivity in difficult areas e.g. Andaman and Nicobar islands and the North-eastern region. Such links are also easy to establish during emergencies such as earthquakes and floods, where the land-based connections are disrupted. Moreover, space lines are quite reliable and excellent in quality, an important feature in long-distance communication. Furthermore, satellites link up not only national but international communications network.

Over 5,750 two-way speech circuits are provided by INSATs, supplementing the ground transmission facilities. Over 220 routes have satellite-based links, including several so-called thin routes serving low but essential traffic requirements.

Satellites are ideal for providing point-to-multipoint links that do not depend on the public service telephone network. Over the last three decades, the power of satellites has gone up 40 times and their transmission capacity by 100. The size of the antennas on ground has steadily shrunk to about 50 cm for reception of TV signals from satellites and 1.5 to 2 m for transmission. Companies and public organisations can set up their own dedicated communications system, using Very Small Aperture Terminals (VSATs) with 4.5m or 7.5m antennas to connect computers, distribute information and set up phone links. There are over 7500 VSATs in operation (1999) in the country. Additional transponders are likely to operate from satellites in the future. A big increase in the number of VSATs is likely, as data transmission of commercial communication networks is gaining momentum.

There is a Remote Area Business Message Network operated by the Department of

Telecommunications (DoT), with about 1000 VSATs. The Network has access to the public data network of DoT, called I-NET. In addition, rural telegraphic services are operated by another network. Several companies, banks, financial institutions and engineering corporations (over 300 as of 1999) have their own VSAT networks (e.g. the Oil and Natural Gas Commission, and the National Thermal Power Corporation). The Reserve Bank of India has a plan to interconnect all banking branches. The National Stock Exchange has its own network. Trading in the VSAT-based stock markets is estimated to be worth several crores of rupees a day.

While satellite television provides a fantastic medium for dissemination of news, information and entertainment as well as cultural enrichment in tune with the multlingual and multireligious, pluralistic society in India, the quality of several programmes (with minor exceptions) has evoked strong disapproval. There is a growing concern about television's impact on human development and values. Several programmes show an increasing trend of absurd gimmicks in the name of mass entertainment, besides vulgar display of sex and violence. Suffocating commercials leave the viewers permanently disappointed with whatever they have. Several promote a life-style of perpetual discontent, which is against the Indian culture. Moreover, the deluge of foreign films is not regarded as a healthy trend by many media watchers.

In urban areas, cable TV distributed by private operators through dish antennas has become popular, as they connect several private channels beamed from satellites. Several competing channels have dislodged the monopoly of Doordarshan.

In 1997 the Government of India issued a policy statement on satellite communications. The policy allows Indian operators to uplink their programmes from the country to Indian and foreign satellites. The INSAT system would be offered to non-governmental users on commercial terms. And Indian private enterpreneurs may establish commercial communication satellites and the government would assist them in their registration with the International Telecommunication Union as Indian satellites. The policy met a long-felt need. There is no longer any need for Indian television companies to uplink their programmes from foreign countries.

Satellites have made a big difference in the provision of television services. Over 85 per cent of the country's population and over 65 per cent of the land mass can be reached by INSAT (1998) through 1020 TV transmitters. Doordarshan operates separate channels for the country's major languages as well as an international channel that can reach an area from West Asia to Southeast Asia.

Satellite television began with direct reception through community viewing sets in selected villages. The experiment was successful but the progress of technology and the spread of terrestrial transmission facilities favoured the reception of channels through transmitters on an individual basis. Still, direct television sets working with INSAT are deployed for community viewing in selected areas in some States (Andhra Pradesh, Bihar, Uttar Pradesh, Maharashtra, Gujarat) and in the North-eastern region.

Notwithstanding the spread of television, India's rural people have yet to get the maximum benefit of the technology. Given the current pattern of utilisation of the TV channels for entertainment, sustained by advertisements, the scope for a massive increase in programmes for rural areas is rather limited. It is therefore proposed to build a separate satellite for rural areas called Gramsat. The satellite is meant for harnessing space technology to serve the underprivileged by utilising the community and cultural strength. It would be possible to introduce programmes for improving the economic conditions and health care in rural areas. It would encourage the participation of gram panchayats and other public institutions as well as non-government organisations.

Another area where satellite link is used is radio networking. Over 200 radio stations can receive signals from INSAT uplinked from selected stations. A few transportable units are also used. Experiments will soon begin on digital audio broadcasts directly from a satellite to radio receivers; the technique would eliminate fading and noise experienced in terrestrial broadcasting.

INSAT is used for transmission and distribution of news and news photo by news agencies. However, satellite-based news reporting from different parts of India has yet to make a significant headway. Yet another service based on INSAT signals is dissemination of the Indian standard time. The service is available round the clock.

With the spread of computers, the use of Internet is fast catching on in India. Effective provision of Internet connections can be ensured by reliable satellite links connecting individual workstations and PCs to databases and on-line service providers in India and abroad. Moreover, community Internet centres are being planned in collaboration with certain States.

The National Informatics Centre (NIC), went into operation in 1988 by switching on its satellite-based computer communication network (NICNET). The capability of the network has been successfully demonstrated in a variety of applications : rural development information systems, decision support information connecting the district headquarters with the State and Central government capitals, plan project monitoring and dissemination of election results. The network has also supported several closed user groups such as the Steel Authority of India Ltd., the Food Corporation of India and the Indian Farmers Fertilizer Corporation Ltd.

NICNET has switched over to a powerful National Info-Highway using Ku band. The network has a control centre which is connected to all its participating units through satellite. Each remote station's antenna has a tracking facility to work with inclined orbit satellites and to adjust the uplink power control to overcome attenuation of signals by rain. The NICNET Info Highway offers many services (e.g. image transmission) without requiring large investments by the users. It will enable users to access the Internet's World Wide Web. The Info Highway is connected to more than 160 different international data networks.

New technologies are on the anvil. Digital TV and data compression technique would allow more TV channels using the same bandwidth. Moreover, direct television to home (DTH) can provide many advantages such as small antenna and independent access to broadcast channels. DTH can improve the quality of distance education and medical facilities available in the rural areas.

The use of satellite TV for education has, however, not caught on in a big way. No doubt, the Indira Gandhi National Open University offers courses in distance education to a large number of students. Given the low quality of education in the schools at all levels, the heavy drop-out rate, especially from government schools, poses a serious threat to the future of the country. The private sector has commercialised education, while the public sector schools suffer for want of adequate resources. An open university can make a difference, provided its reach is expanded and the standard of the courses and of nonformal educational telecasts is upgraded. INSAT-3B is designed to provide some of its capacity exclusively for interactive training and developmental communication. The service, Vidya Vahini, would be under the Swaran Jayanthi Vidya Vikas Antariksh Upagraha Yojana. Telemedicine is also expected to be introduced in remote areas.

Empowerment of people at the grass roots level has become a distinct possibility with the emergence of interactive television. Using such a forum, even a lowly placed person can question, seek clarification and comment on the views and decisions of the highest executive or high-level experts. An ongoing project involving tribal people in the Jhabua district of Madhya Pradesh in interactive television programmes may offer some useful lessons on the techniques adopted.

There is considerable scope of for satellite-based, interactive mode of communicating development messages and training programmes. Banks, companies and industrial units can arrange training programmes for their staff in an economical way; the best of training skills can be brought to the maximum number of trainees in a short period.

Monitoring the Weather

The daily satellite picture of the weather over India shown on television is provided by the INSAT system. Weather monitoring is an important function of the INSATs. The system provides round-the-clock, half-hourly, synoptic images of the weather conditions such as cyclones, temperature of the sea-surface and cloud-tops and snow cover the country and the adjoining land and sea areas. The satellite also collects and transmits data from unattended remote platforms. Timely warnings of cyclones, floods and storms are issued.

An indigenous instrument called Very High Resolution Radiometer (VHRR) provides visible and infrared images of the weather. INSAT-2A and 2B carried the instrument, designed to give a better performance than the first generation INSAT-1 in terms of spatial resolution (two km in the visible channel and 8 km in the infrared channel as against 2.75 km and 11 km, respectively).

The VHRR on INSAT-2E has a new feature : a water vapour detecting channel.

It is designed to detect moisture in the middle levels of the atmosphere at a spatial resolution of 8 km in the infrared channel. The VHRR has also a charge coupled device to provide video output of the visible and infrared radiation. The VHRR is designed to provide for the first time continuous surveillance of the cloud cover and surface features during day time. Data from the instrument are expected to yield regional/ State level estimates of wheat acreage in Punjab, Haryana and Western Uttar Pradesh; sorghum acreage in central Maharashtra and rice acreage in southern and eastern India.

Some problems were reported with a mechanical part of the VHRR and with the control of temperature of the infrared detector, though the solar panels are fixed on only one side of the satellite to reflect the heat away from the weather monitoring device. A satellite exclusive to weather monitoring, possibly with radar, may also be designed in the future. The importance of radar that can penetrate clouds cannot be overemphasised, especially in times of flood, when the water level does not indicate the true extent of the flood. For example, Canadian RADARSAT images were found useful in evaluating the Orissa flood in 1999.

INSATs have a unique disaster-warning system. The satellites disseminate cyclone warnings to the affected areas. Selected receivers in vulnerable areas are activated by a signal from INSAT and a loud siren is sounded. Cyclone warnings are provided in the local language.

Search and Rescue

India is the first country to join the worldwide search and rescue system with a geostationary satellite service. Unlike satellites in the lower Earth orbits, a powerful geostationary satellite can detect distress signals in near real time and the mission control can relay the alert to other control centres for search and rescue operations.

In satellite-aided search and rescue operations, terminals in Bangalore and Lucknow detect distress signals from ships and planes and alert the Navy, the Air Force, the Coast guard and airports for initiating rescue operations. The alert service is provided to other countries also.

Dr. Sarabhai envisaged satellites as a means of catching up with the advanced countries in terms of modern telecommunications, television and weather forecasting. Even as the conventional modes of telecommunications and television are being upgraded by satellites, the birds in the orbit have acquired a new role of taking the country into a new age of knowledge and enlightenment propelled by the Internet.

Will this technology make a difference to the life of the majority of the people ?

The answer is yes, but only if there is a national commitment to bring the benefits to the common man, at an affordable price.

Controls at Finger-tips

A visit to the Master Control Facility (MCF) in Hassan in Karnataka makes one proud of India. Here is a place where young Indians are in charge of one of the most sophisticated technologies viz., controlling and commanding satellites which are out there some 36,000 km away. The remarkable passion for detail and accuracy that governs the daily routine of monitoring and controlling satellites at the Facility is perhaps a legacy, a tradition continued over generations which found its finest expression in the sculptural friezes in stone done in astonishing detail in the neighbouring Belur and Halebedu.

MCF takes control of a satellite within minutes of its injection into the orbit and continues to control it thereafter. Three ground antennas are in constant touch with the satellites parked over the equator in the slots marked by the internationally allotted longitudes. MCF monitors some 400 parameters of a satellite (e.g. power, fuel, stability etc.). The data on the satellite's health are monitored every eight seconds. The attitude and control system typically consists of Earth sensors, sun sensors, an inertial reference unit that detects the deviations in the orbit, momentum wheels and reaction wheels. Control thrusters, which are normally used once in 80 days, virtually eliminate any deviations from the planned inclination of the orbit.

Bipropellants (combination of monomethyl hydrazine and mixed oxides of nitrogen) are used in the thrusters for raising the orbit and controlling the attitude.

With a view to extending the range of ground control for the geosynchronous rocket missions, India has set up a telemetry, tracking and command station for launch vehicle and satellites at Biak in Indonesia and in Brunei.

The ISRO Telemetry, Tracking and Command Network (ISTRAC) in Bangalore controls near-Earth and sunsynchronous satellites. Other ground control stations are in Sriharikota, Lucknow, Car Nicobar and Thiruvananthapuram, besides a mobile station in Mauritius. The ground stations are connected to the control centre in Bangalore through voice and data links.

An alert and efficient team of young experts at the controls accurately calculates the orbit and altitude, precisely predicts the transit of the satellites, tracks them and formulates the orbit changes, when needed.

For example, ISTRAC monitors IRS-1C in 10 out of its 14 orbits in a day and gets the data for the rest of the orbits from other stations in South Africa, Germany and the United States.

About 1000 parameters (e.g. velocity, temperature) of the satellite are recorded and some 50 critical data are closely watched. The orbit is maintained within 200 metres of the satellite's nominal location in space and within one kilometer of its ground track.

ISTRAC tracks rockets too. A laser and optical tracking facility is available for this purpose at the Vainu Bappu Astrophysical Observatory at Kavalur in Tamil Nadu.

During the Leonid meteoroid shower in 1998 and 1999, as the Earth went through the rubble of Comet Tempel-Tuttle, MCF and ISTRAC took precautionary measures to protect its six INSATs, four IRS and one SROSS-2 scientific satillites. The controllers oriented the solar panels in such a way that they showed minimum surface area to the meteoroids. Operations of the X-ray detector on IRS - P3, the Gamma ray detector on SROSS-2 and the PAN camera on IRS-1C were suspended. The meteoroids did not affect the satellites.

11

PURSUIT OF KNOWLEDGE

Space technology is utilised not only for enhancing material benefits but also for the pursuit of knowledge. A sense of curiosity about the mysteries of Nature triggers the quest for knowledge, an essential dimension of human development. And knowledge is power.

Even before the Space Age dawned in 1957, several significant studies were made in India of the ionosphere, extending from 50 km to 1000 km in the atmosphere. Dr. Meghnad Saha (1893-1956) was famous for his studies of the sun and theories about the ionosphere, useful for radio wave propagation. The physics of the upper atmosphere attracted many young persons.

The nearest atmospheric region to the Earth's surface is called the troposphere (upto 16 km). Above the troposphere is the stratosphere upto 50 km. The region above the stratosphere is known as the meosphere upto 90 km.

The country's space programme began with the pursuit of knowledge. A phenomenon called the equatorial electrojet over Thumba in the ionosphere attracted the scientists. It is a high-intensity current flowing from east to west at a height of 110 km over the magnetic equator near Thumba. It was the target of studies by the initial sounding rockets from Thumba. The strong currents, it was believed, enhanced the diurnal variations of the Earth's magnetic field near the magnetic equator. The electrojet is in the so-called E-region of the ionosphere (90-150 km). At a height of about 100 km, there is another phenomenon called Sporadic E which appears in the day time within 4° on either side of the magnetic equator. The electron density in the ionoshpere also varies. Scientists call them "irregularities". The first Indian payload on board the French Centaure rocket sent from Thumba was designed to measure the electrons and temperatures at high altitude.

The Rohini series of sounding rockets with their scientific payloads has been used for studying the atmosphere, including the ionosphere. RH - 200, the smallest of the series (200 indicates the diameter in millimeters) has been extensively used for launching meteorological payloads of 10 kg to about 75 km attitude. RH-300 can take a payload of 50 kg to an altitude of 110 km and is useful for investigating the ionosphere. Heavier payloads (60 kg) are used for studying the ionosphere at a height of 150 km. Rohini - 560, a two-stage rocket, can launch a 80 kg payload to 350 km for high-altitude studies. RH-560 Mark II, the largest in the series, is also used for the study of the ionosphere.

Two RH-300 MK II rockets were launched to study the ionosphere during the Leonid meteor showers through which the Earth passed in November 1999. One of the rockets was launched two days later to get reference data on ionospheric features in the absence of the Leonid showers. Simultaneously, observations were made at Tiruvananthapuram, Sriharikota and the Osmania University in Hyderabad. The data were analysed at the Physical Research Laboratory in Ahmedabad.

Rohini rockets have been used for scientific studies under several programmes such as the Indian Middle Atmospheric Programme and the monsoon experiment called MONEX under the Global Atmospheric Research Programme. Several countries have regularly utilised the facilities in Thumba for launching their scientific payloads. Russian two-stage rockets, known as M-100 were regularly launched to study the upper winds and the atmosphere. The eastern space range at Sriharikota is also made available for sounding rocket programmes.

The Space Physics Laboratory in Tiruvanathapruam is one of the very active centres for atmospheric research. The Physical Research Laboratory in Ahmedabad also conducts experiments to study the atmosphere.

A study of the Earth's atmoshpere has become essential to understand the complex, interactive physical, chemical and biological processes that regulate the total Earth system and its unique environment. In 1986 the United Nations, under the aegis of the International Council of Scientific Unions, initiated the International Geosphere - Biosphere Programme. As part of the programme, ISRO indentified several projects including high-altitude balloon programmes. Huge balloons (typically 100,000 cubic metres in volume, while in the air) are sent up with canisters of titanium tetrachloride, methanol and water. The canisters are burst open at different altitudes and the chemical puffs released are photographed from the ground. The experiment is meant to study the transport of pollutants in the stratosphere and the energy transfer from the sun to the Earth. The air samples are recovered and analysed to study the extent of trace gases such as freon, nitrous oxide, methane, carbon monoxide and carbon dioxide. Increasing amounts of trace gases in the atomosphere are causing concern, as they are likely to destroy the ozone and contribute to global warming.

Several institutions collaborate with ISRO in these studies. They include the Tata Institute of Fundamental Research, the German Space Research Establishment and the Max Planck Institute for Aeronomie (Germany).

Other studies under the Geopshere-Biosphere Programme, initiated in the country, include climate modelling, land-air-ocean interactions and atmospheric minor constituents.

Several facilities, set up by ISRO, are engaged in the study of the atmosphere in the Indian tropical region. A national facility for atmospheric and ionospheric studies has been set up at Gadanki near Tirupati in Andhra Pradesh known as the Mesosphere - Stratoshpere - Troposphere (MST) Radar facility. It is used for the study of atmospheric dynamics, atmospheric pollutant dispersal, upper air turbulence etc. The radar is capable of probing different regions of the atmosphere. It can also make wind measurements accurately. The data would be useful for supporting satellite launches from Sriharikota.

India and France will jointly develop a small scientific satellite, called Megha Trophiques, for atmospheric studies in the tropics. India will develop one of the three sensors of the satellite, designed to measure rain and cloud features. India's PSLV will launch it in 2005 into a 800 km orbit. The satellite is designed to collect data on water vapour, precipitation and radiation in the tropical region. The data could help in the prediction of tropical cyclones.

Celestial Wonders

The country's first satellite-related experiments studied the ionosphere, solar radiation and celestial X-rays. The ionosphere probe was designed to study the heat budget in the ionosphere at different periods of the day and in different seasons and to measure the ultraviolet radiation background in the night sky. The ultraviolet glow enveloping the Earth, seen by astronauts from the moon, holds several clues to a better understanding of the Earth's atmosphere.

The solar radiation experiment aimed at the detection of possible emission of neutrons and gamma rays from the sun during the sun's quiet periods. It also looked for gamma rays during stellar explosions.

The X-ray payload on Aryabhata had two telescopes: one to see particular sources of X-rays, and another to scan diffused X-rays.

Even during the short period of its working, the payload scanned the X-ray sources in Crab Nebula, 3000 light years away. The data showed evidence of X-rays in the centre of our galaxy.

IRS-P3 carried an X-ray astronomy payload in 1996. A binary star, known as Cygnus X-1 was studied. The X-ray source is believed to be a black hole.

Indian scientists from the Tata Institute of Fundamental Research, in collaboration with Canadian investigators, made an interesting discovery from one of their balloon flights. They found that Scorpius X-1, the first X-ray source to be discovered outside the solar system in 1962, was in fact a pulsar or a pulsating neutron star.

ISRO has designed and developed a series of small satellites for conducting experiments not only in space technology but also in basic sciences. Under the programme, the Stretched Rohini Satellite Series (SROSS-2) was inaugurated by an ASLV in 1994. The payload was designed to detect gamma ray bursts and to study the upper ionosphere.

Gamma rays yield information on the interstellar medium and cosmic rays. Scientists from eight universities were provided facilities to process and analyse the data.

Scientific workshops convened by ISRO are designed to generate proposals on scientific satellite experiments in the future.

A vibrant space programme cannot be sustained without the active participation of the youth, especially those in the higher academic institutions. The Deparment of Space supports research, educational and scientific activities in universities by initiating projects involving talented youngsters.

Even as space missions are designed to probe cosmic puzzles, the challenge nearer home lies in a better understanding of the atmosphere. As the world's population has crossed the six-billion mark, the sustainability of human beings on the Earth depends on the impact they make on its fragile ecosystem and enviroment. Studies of the atmosphere would reveal the nature of that impact and give a timely warning for taking corrective measures.

Indians in Space

Indian youth have demonstrated their capability in going into space in an effort to unravel the mystery of the new frontier and seek new knowledge.

An Indian cosmonaut scripted his place in history by doing *Pranayama, stithikaran vyayama* (stabilising exercise) and three *asanas* viz., *padahastha, parimitra trikona* and *ustra.* He is Squadron-Leader Rakesh Sharma of the Indian Air Force, who went into Earth orbit in a Russian space station Salyut-7 on 3, April 1984. He was the world's 138th cosmonaut and India became the 14th nation to have sent a man into space. His colleagues in orbit were Yuri Malyshev and Gennady Strekolov. They went in Soyuz-T11 (a smaller spacecraft) and returned on April 11, after eight days in space in Soyuz T-10 Rakesh and his colleague, Ravish Malhotra, underwent a vigorous training schedule prior to the final selection of Rakesh.

Rakesh proved the efficacy of Indian exercises in controlling muscles and blood circulation in manned space missions. The virtual absence of gravity in space near Earth causes some basic changes in the human body. The regular *yoga* practice of Rakesh is believed to have contributed to his cheerful disposition throughout the mission. Though his pulse rate shot up from 72 to 102 during the lift-off, it became normal after seven minutes. There was a new menu every day including mango and *pulav*. Some of the items were specially prepared by the Defence Food Research Laboratory in Mysore.

Rakesh performed an important experiment on board the spacecraft. It related to the formation of a new alloy in space by heating silver and germanium in the onboard furnace. Rakesh took many photographs of India using a wide angle, multi-spectral camera skillfully. Each pass over India was in a different orbit, lasting two to ten minutes. Rakesh even spotted some Indian mountaineers climbing Mt. Everest!

In 1997 an Indian-born woman astronaut went aboard the space shuttle, Columbia. She is Ms. Kalpana Chawla, born in India in 1962. She studied aerospace engineering and went to the U.S. for further studies. She earned a Ph.D. in aerospace engineering. At 25, she became a pilot and evinced a keen interest in space flights. She was eventually selected for astronaut training. In November

1997 she made her maiden space flight as a mission specialist on board the US space shuttle, Columbia, on a 16-day mission. She participated in some of the experiments on board. She released a satellite designed for watching the sun. Initially, the satellite did not function as planned and she could not grapple it with the robot arm. But she handled the situation calmly and acted correctly on the instructions given by Mission Control. She travelled 10.4 million km in space, and landed on December 5, 1997. The mission lasted 15 days, 16 hours, 34 minutes.

Rakesh and Kalpana have proved that Indian youth can go into space and work there, if only an opportunity is given to them.

12

THE CHALLENGE CONTINUES

India's space programme has shown that the country's young men and women can master new technologies and design and develop world class products and processes, given the opportunity and resources. It is remarkable that the younger generation of scientists and engineers has imbibed the ideals of Dr. Sarabhai in harnessing the technology for promoting human development. A greater challenge lies in the road ahead, as commercial considerations tend to determine priorities in favour of the privileged classes.

As India's population has crossed the one-billion mark, the basic challenge would be provision of easy and equitable access to the benefits of space technology to the vast majority of the people. A fair and realistic use of the technology cannot but take into account certain harsh realities. For example, about 40 per cent of the country's population is below the age of 14 and the national literacy rate is 75.6 per cent for men and 54.1 per cent for women. And the quality of education is mostly unacceptable. Again, if the work force has to be in line with the new demands of the Information Age, frequent on-the-job updating of skills and knowledge is inevitable. As the traditional, formal schooling leads to a heavy percentage of drop-outs, non-formal education of quality should be brought within the reach of all.

Satellite imageries have highlighted the contours of the challenge facing the country. It is truly said that satellites have rediscovered India. But the resulting imageries reveal vast areas of wasted land, dried-up irrigation channels, silted reservoirs, diminishing forests and ever-increasing pollution of the atmosphere and the natural resources.

Again, the television system, sustained by massive advertisement revenue, is only strengthening the divide in society between the privileged classes and the vast majority of have-nots by perpetuating a never-ending hunger for goods and services, not all of which are really necessary. The entertainment and even the general knowledge programmes on television reveal an unacceptable obsession with inconsequential details, besides glorifying violence and sex. While the public sector television continues to be generally dull and unprofessional, the private sector has, with a few exceptions, embraced irrelevant western modes of behaviour, food habits and family values. The slow progress in using television for education, both formal and non-formal, is likely to continue, unless distance education graduates from being a poor cousin of the conventional graduate to the status of a respectable companion.

Space activities are thus too many and too important to be the concern of any one or even some government departments. The private sector, non-governmental agencies, social institutions should all come forward and bring about a change in society that would accept modern technology and utilise it for the greater benefit of many rather than the entertainment of a few. Space-based technology needs to be integrated with human development. The process calls for a change away from the age-old administrative practices, profit-driven educational institutions, politically obsessed planning and a work culture that encourages indifference and lack of commitment to excel.

Space activities are increasingly justified on a commercial basis. While this approach has the merit of promoting cost-consciousness, it may affect the commitment to human development through space activities. A touch of idealism to care for the human side of progress is urgently required. A profit-oriented approach, justifiable on economic grounds has to be modified to serve the needs of those who lack the capacity to pay.

Training in numerous disciplines has to be taken up on a vast scale. The Internet has to spread to rural India. Again, a physical connection to an information network may be easier to provide than access to a cross section of the people, given the continuing social barriers against people's participation without discrimination on the basis of caste or language. The introduction of better agricultural practices should lead to a sustainable development of resources. A qualitative difference in education and health care has yet to emerge in a big way.

The broad aims of space applications that would promote human development have been spelt out at the Third United Nations Conference on Peaceful Uses of Outer Space held in Vienna in July 1999. The Conference envisaged measures such as :

- promotion of literacy and rural education through satellite-related infrastructures ;
- promotion of universal access to space-based communication services ;
- improved public health services including tele-medicine in rural areas ;
- provision of enhanced access to space-based navigation and positioning systems;
- support to sustainable development of natural resources ;
- enhanced access to and affordability of satellite imagery for management of the Earth's natural resources ;
- better environmental monitoring to check or prevent pollution caused by human activities on the Earth as well as in space; and
- capacity-building through training teachers and decision-makers ;

Space technology may be compared to the launching of a satellite; it can be put into the orbit in a matter of a few minutes; but for the rest of its active life, the satellite is at the mercy of many natural forces, and requires constant care and control. It is relatively easier to install the hardware in space technology but its social acceptability and use in the right direction need constant vision and revision by an enlightened leadership in the scientific, political, economic and social fields. In short, the technology will only reflect our aims and policies. The bottom line is whether those who decide are driven by some selfless ideals to serve the country. The challenge lies not only in enabling our youth acquire the knowledge and skills for mastering the space technology but also in educating them to imbibe the ideals of service to the country and concern for the under privileged. Only when this challenge is met effectively can space promote human development. Our younger generation, it is hoped, would imbibe such ideals.

Prof. Satish Dhawan, doyen of India space programmes, who has carried on the mantle of Dr. Sarabhai, once said *"Space technology cannot by itself generate values and meet social objectives, but if handled firmly and imaginatively, it might subserve them"*. This pertinent observation is worthy of deep reflection.

Meanwhile, the International Space Station, now in orbit, promises to open a new window on human development. For the first time in history, humans will try to rediscover their body and mind under prolonged micro-gravity. New medicines, vaccines and materials may change human life and business beyond anything imaginable now. Future generations may well witness a new turning point in human development triggered from space.

INDIA IN SPACE : A TIME LINE

1962 : Indian National Committee for Space Research (INCOSPAR) formed by the Department of Atomic Energy and work on establishing the Thumba Equatorial Rocket Launching Station (TERLS) started.

1963 : First sounding rocket launched from the Thumba Equatorial Rocket Launching Station (TERLS) [November 21, 1963].

1965 : Space Science & Technology Centre (SSTC) established in Thumba.

1967 : India's first rocket, Rohini-75 launched from Satellite Telecommunication Earth Station set up at Ahmedabad.

1968 : TERLS dedicated to the United Nations [February 2, 1968].

1969 : Indian Space Research Organisation (ISRO) formed under Department of Atomic Energy [August 15, 1969].

1972 : Space Commission and Department of Space (DoS) set up. ISRO brought under DoS [June 1, 1972].

1972-76 : Air-borne remote sensing experiments.

1975 : First Indian Satellite, Aryabhata, launched [April 19, 1975].

1975-76 : Satellite Instructional Television Experiment (SITE) conducted.

1977 : Satellite Telecommunication Experiments Project (STEP) carried out.

1979 : Bhaskara-I, an experimental satellite for Earth observations, launched [June 7, 1979].

First Experimental launch of SLV-3 with Rohini Technology Payload on board [August 10, 1979]. Satellite could not be placed in orbit.

1980 : Second Experimental launch of SLV-3. Rohini satellite successfully placed in orbit [July 18, 1980].

1981 : First developmental launch of SLV-3, RS-D1 placed in orbit [May 31, 1981].

APPLE, an experimental geostationary communication satellite successfully launched [June 19, 1981].

Baskara-II launched [November 20, 1981].

1982 : INSAT-1A launched [April 10, 1982]. Deactivated on September 6, 1982.

1983 : Second developmental launch of SLV-3. RS-D2 placed in orbit [April 17, 1983].

INSAT-1B, launched [August 30, 1983].

1984 : Indo-Soviet manned space mission [April 1984].

1987 : First developmental launch of ASLV with SROSS-1 satellite on board [March 24, 1987]. Satellite could not be placed in orbit.

1988 : Launch of first operational Indian Remote Sensing Satellite, IRS-1A [March 17, 1988].

INSAT-1C launched [July 21, 1988]. Abandoned in November 1989.

Second developmental launch of ASLV with SROSS-2 on board [July 13, 1988]. Satellite could not be placed in orbit.

1990 : INSAT-1D launched [June 12, 1990].

1991 : Launch of second operarional Remote Sensing satellite, IRS-1B [August 29, 1991].

1992 : Third developmental launch of ASLV with SROSS-C on board [May 20, 1992]. Satellite placed in orbit.

INSAT-2A, the first satellite of the indigenously-built second-generation INSAT series, launched [July 10, 1992].

1993 : INSAT-2B, the second satellite in the INSAT-2 series, launched [July 23, 1993].

First developmental launch of PSLV with IRS-1E on board [September 20, 1993]. Satellite could not be placed in orbit.

1994 : Fourth developmental launch of ASLV with SROSS-C2 on board [May 4, 1994]. Satellite placed in orbit.

Second developmental launch of PSLV (PSLV-D2) with IRS-P2 on board (October 15, 1994) Satellite successfully placed in polar sunsynchronous orbit.

1995 : INSAT-2C, the third satellite in the INSAT-2 series, launched [December 7, 1995].

Launch of third operational Indian Remote Sensing Satellite, IRS-1C [December 28, 1995].

1996 : Third developmental launch of PSLV with IRS-P3 on board [March 21, 1996]. Satellite placed in polar sunsynchronous orbit.

1997 : INSAT-2D, fourth satellite in the INSAT series, launched [June 4, 1997]. Becomes inoperable on October 4, 1997. [An in-orbit satellite, ARABSAT-1C, later renamed INSAT-2DT, was acquired in November 1997 to partly augment the INSAT system].

First operational launch of PSLV with IRS-1D on board [September 29, 1997]. Satellite placed in orbit.

Liquid propulsion strap-on stage of GSLV successfully qualified [March 5, 1998].

First cryogenic stage for GSLV received from Russia [September 20, 1998].

1999 : INSAT-2E placed in orbit.

PSLV-C2 successfully places IRS-P4 (Oceansat), Kitsat-3 [South Korean Satellite] and DLR-TUBSAT [German satellite] in correct orbits.

2000 : INSAT-3B launched from Kourou and placed in orbit.

2001 : First Developmental test flight of GSLV aborted on the launching pad (March 28)

GSLV-D1 successfully launched, (April 18). GSAT-I, experimental satellite, placed in the geosynchronous transfer orbit

GLOSSARY

Acceleration	Rate of change of velocity.
Antenna	A conductor for radiating or receiving radio waves.
Apogee	The point at which a satellite is farthest from the Earth: the opposite of perigee.
Attitude	The position of the axis of a satellite with respect to (i) its orbital plane or (ii) the Earth's surface, or (ii) any fixed set of co-ordinates.
Bandwidth	The width of a frequency band (e.g. MHz).
Bipropellant	A propellant with two chemical components (fuel and oxidiser) stored separately and combined for combustion.
Bit	A unit of information, electronically transmitted (as binary digits), corres-ponding to 1 or 0 in a computer.

C-band	Radio frequency and of 3.9-6.2 GHz with wavelengths of 4.84-7.69 cm.
Cosmic rays	High-energy subatomic particles bombarding the Earth from space. On colliding with the atmosphere, they produce many different kinds of low energy radiation.
Cryogenic propellant	A liquid propellant (fuel or oxidiser) formed by the liquefaction of a gas when cooled to very low (cryogenic) temperatures.
Data	Any information usually sent in the form of binary bits.
Doppler effect	Shifting of the wavelength or frequency of a receding source of light (or sound) towards the red (long wavelengths) end of the spectrum and towards the blue (if it nears the observer).
Earth sensor	A device used to establish a spacecraft's attitude relative to the Earth.

wEarth station	Antennas and related equipment on the ground that contact a satellite.
Geosynchronous/geostationary Earth orbit (GEO)	A circular orbit in the same plane as the Earth's equator with the same period of rotation as that of the Earth at a height of 36,000 km.
Geostationary transfer orbit (GTO)	An elliptical Earth orbit used for transfer of a spacecraft from a lower orbit to GEO.
Giga Hertz (GHz)	Billion Hertz.
Geographic information system (GIS)	A computer-based information system that can input, manipulate, and analyse geographically referenced maps as well as tabular data. Satellite imagery is used in GIS for natural resource managment.
Gyroscope	A guidance system, consisting of a rapidly spinning wheel, suspended in a special frame.

	The axis of rotation remains the same, irrespective of the frame's movement.
Hertz	Cycles per second, named after Heinrich Hertz.
Inertial guidance	Guidance in aerospace, which does not depend on any contact with the ground.
Infrared	Electromagnetic radiation pertaining to energy in the 0.7-100 micrometre wavelength region. Often subdivided into near-infrared (0.7-1.3 micro metres), middle-infrared (1.3-3 micro metres) and far-infrared (7.0-15.0 micro metres). Far infrared is also known as thermal or emissive infrared.
Ionosphere	Region in the upper atmosphere where part of the gases gets ionised. This region reflects radio waves.
Low earth orbit (LEO)	A nominally circular orbit of low altitude and short period (about 90 minutes).

Mega Hertz (MHz)	One million Hertz.
Micrometre	One millionth of a metre (the term micron used to denote it earlier was discontinued by international agreement in 1967).
Microwave	Radio waves above 100 Mega Hertz which travel straight as light waves used in telecommunication.
Momentum wheel	A wheel in a three-axis stabilised spececraft used to provide gyroscopic stability and attitude control.
Monopropellant	A single chemical propellant.
Multispectral imagery	Indicates imagery formed, usually simultaneously, in more than one spectral region and analysed jointly.
Multispectral scanner	An instrument for obtaining information on radiation emitted or reflected at different wavelengths by objects.

Nanometre (nm)	Billionth of a metre.
Orbit	The path of a body or particle under the influence of a gravitational or other force.
Panchromatic	Refers to the sensitivity of films to a single broad band (e.g. the entire visible part of the spectral bands).
Payload	Scientific or other equipment/passenger carried by spacecraft/airplanes.
Perigee	The point of closest approach to the Earth of a satellite.
Pitch axis	Axis parallel to the north-south direction of the Earth.
Propellant	A liquid or solid substance burned in a rocket for developing thrust.
Pulsar	Pulsating radio source.
Remote sensing	Process by which features or objects on the Earth are sensed remotely by satellites or rockets.

Reaction wheel	A wheel used to control the attitude of three-axis stabilised spacecraft.
Roll axis	Axis in the direction of the motion of a satellite or rocket.
Space	Universe outside the Earth's atmosphere.
Sunsynchrosnous orbit	Nominally a retrograde, quasi-polar near-Earth orbit in which a satellite crosses the equator always at the same local time and appears at the same sun angle.
Telemetry	Measurement of the performance of a rocket or satellite and transmitting the information to a ground station.
Three-Axis stabilised Satellite	A satellite that is kept stable with the help of an attitude control system aligned to its pitch, roll and yaw axes.
Transponder	A receiver-cum-transmitter on a satellite, which

	receives, filters, amplifies and transmits a signal (voice, data or TV).
Uplink	Communication path from an Earth station to a satellite.
X-band	Radio frequency band of 5,200-11,000 MHz with wavelengths of 2.75-5.77 cm.
Yaw axis	Axis of a satellite's direction to the centre of the Earth.

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